Supplementary Information for

Detecting irrigation signals from SMAP L3 and L4 soil moisture: A case study in California's Central Valley

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This PDF file includes:

Section S1 to S10

Brief description of Supplementary Information contents:

Section S1. Sensitivity analysis of Pearson's Correlation Coefficient R thresholds for evaluating variability consistency

Section S2. Verification of climatological consistency between SMAP L3_E and L4 in non-irrigated grid cells sampled based on a fixed-step interval sampling

Section S3. Sensitivity analysis of alternative irrigated and non-irrigated grid cell pairs

Section S4. Time series of differences between SMAP L3_E and L4 for selected grid cells

Section S5. Validation on consistency of temporal variability between SMAP L3_E and L4 in irrigated grid cells

Section S6. Map of SMAP's irrigation signals in SV

Section S7. Elevation map for Central Valley, California

Section S8. Scatterplots of comparison between the IS map and two benchmark maps under different thresholds of variability judging Correlation Coefficient R values

Section S9. Google Earth image showing intensive urbanization in region (iii), SJV

Section S10. Map of SMAP's irrigation signals in Snake River Basin (SRP)and Nebraska High Plain (NHP)

S1 Sensitivity analysis of Pearson's Correlation Coefficient *R* thresholds for evaluating variability consistency

S1.1 In San Joaquin Valley (SJV)
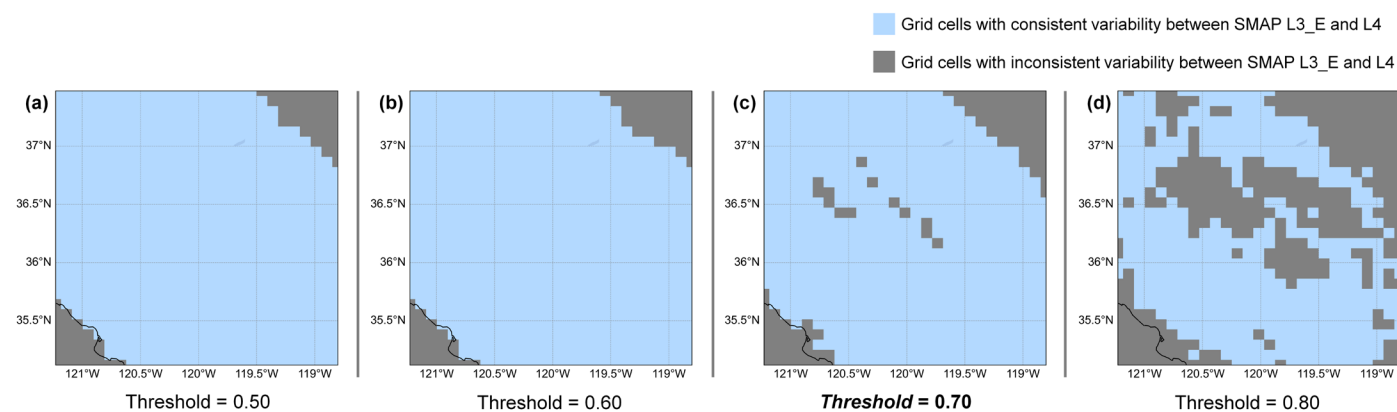
Figure S1-1. Grid cells with consistent/inconsistent variability under different thresholds for Pearson's Correlation Coefficient *R* in SJV.

S1.2 In Sacramento Valley (SV)
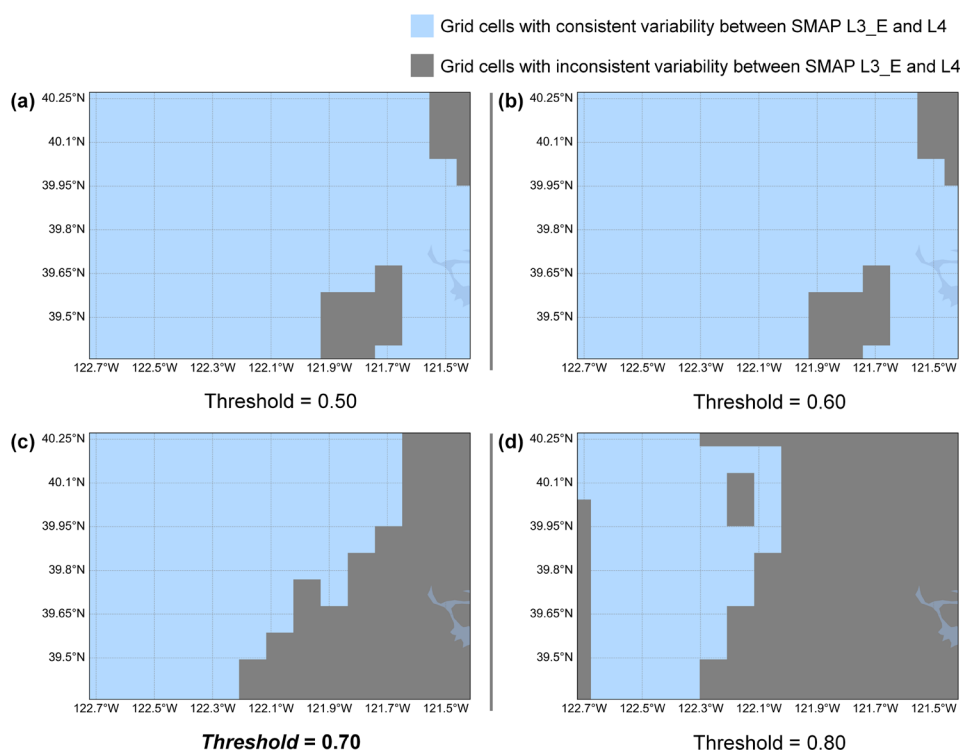
Figure S1-2. Grid cells with consistent/inconsistent variability under different thresholds for Pearson's Correlation Coefficient *R* in SV.

S2 Verification of climatological consistency between SMAP L3_E and L4 in non-irrigated grid cells sampled based on a fixed-step interval sampling

S2.1 Grid cell locations
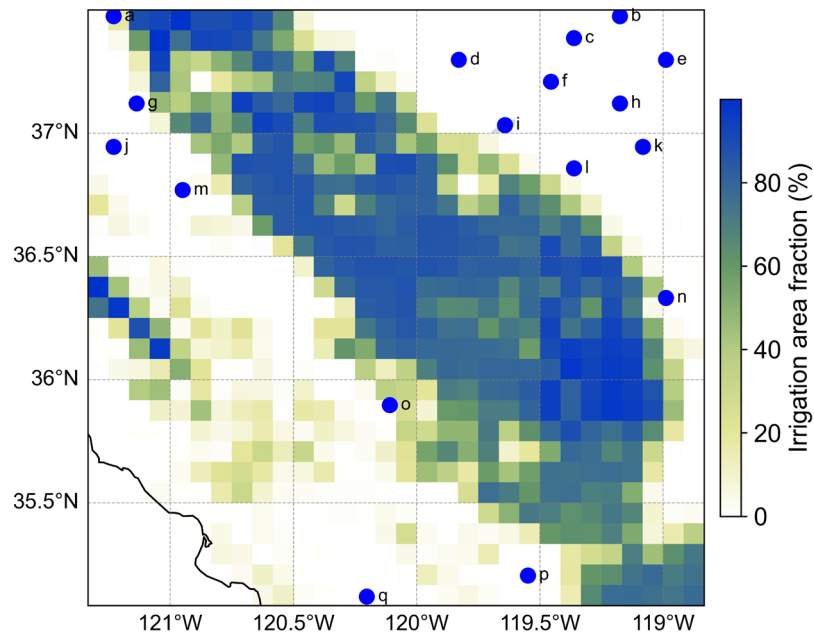
Figure S2-1. Locations of sampled non-irrigated grid cells in SJV (12-step interval).
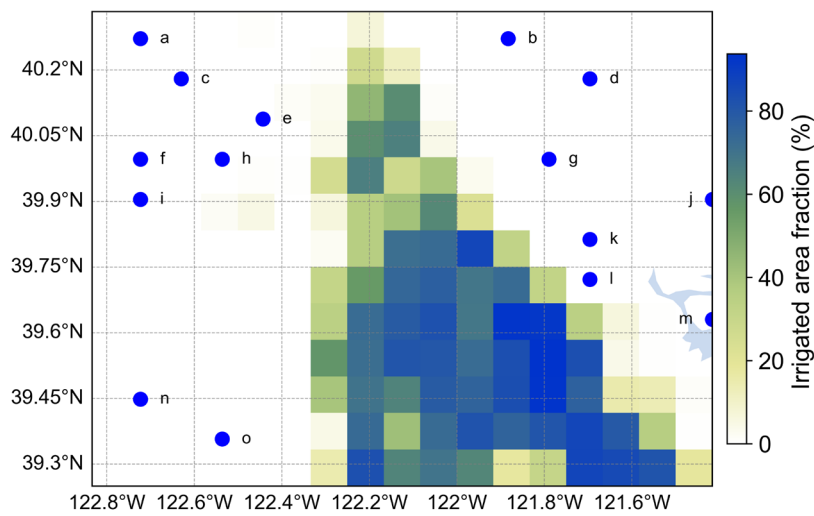
Figure S2-2. Locations of sampled non-irrigated grid cells in SV (8-step interval).

S2.2 Verification in SJV
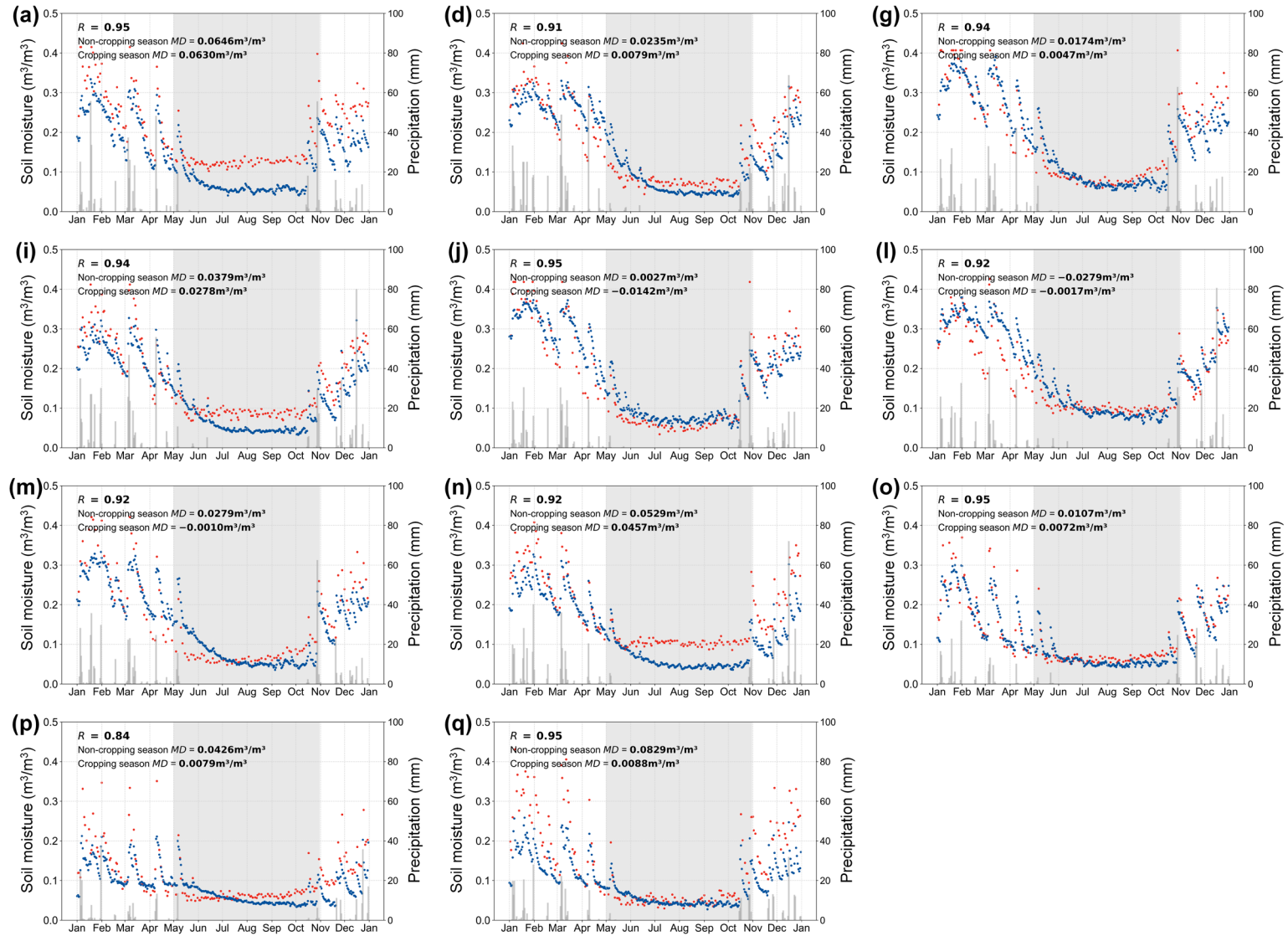
Figure S2-3. Surface soil moisture from SMAP L3_E and L4 in sampled non-irrigated grid cells in 2016. Red dots represent L3_E soil moisture and blue dots represent SMAP L4 soil moisture (left axis), and gray bars indicate precipitation (right axis). Light gray shaded area represents the cropping season. See Fig. S2-1 for grid cell locations.
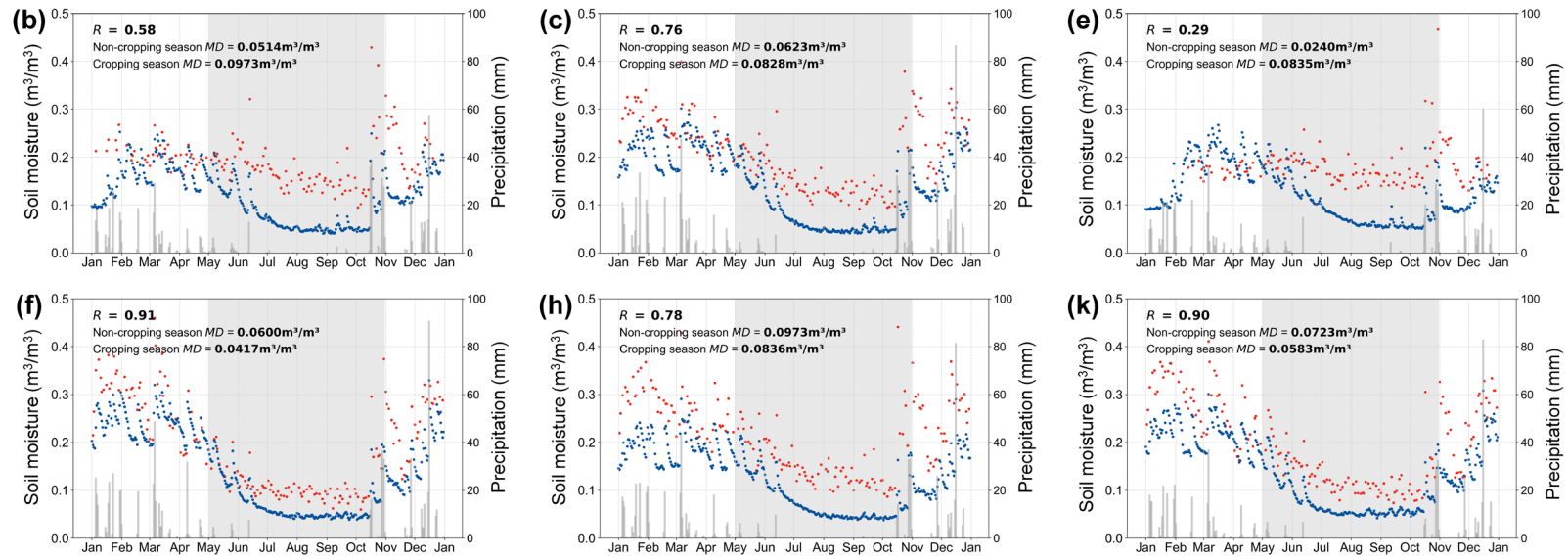
Figure S2-4. Surface soil moisture from SMAP L3_E and L4 in sampled non-irrigated grid cells in 2016 (Sierra Nevada mountains). Red dots represent L3_E soil moisture and blue dots represent SMAP L4 soil moisture (left axis), and gray bars indicate precipitation (right axis). Light gray shaded area represents the cropping season. See Fig. S2-1 for grid cell locations.

Note: The grid cells shown in Fig. S2-4 (including grid cells b, c, e, f, h, and k) are located in the seasonally snow-covered Sierra Nevada mountains, where differences between SMAP L3_E and L4 are expected.

S2.3 Verification in SV
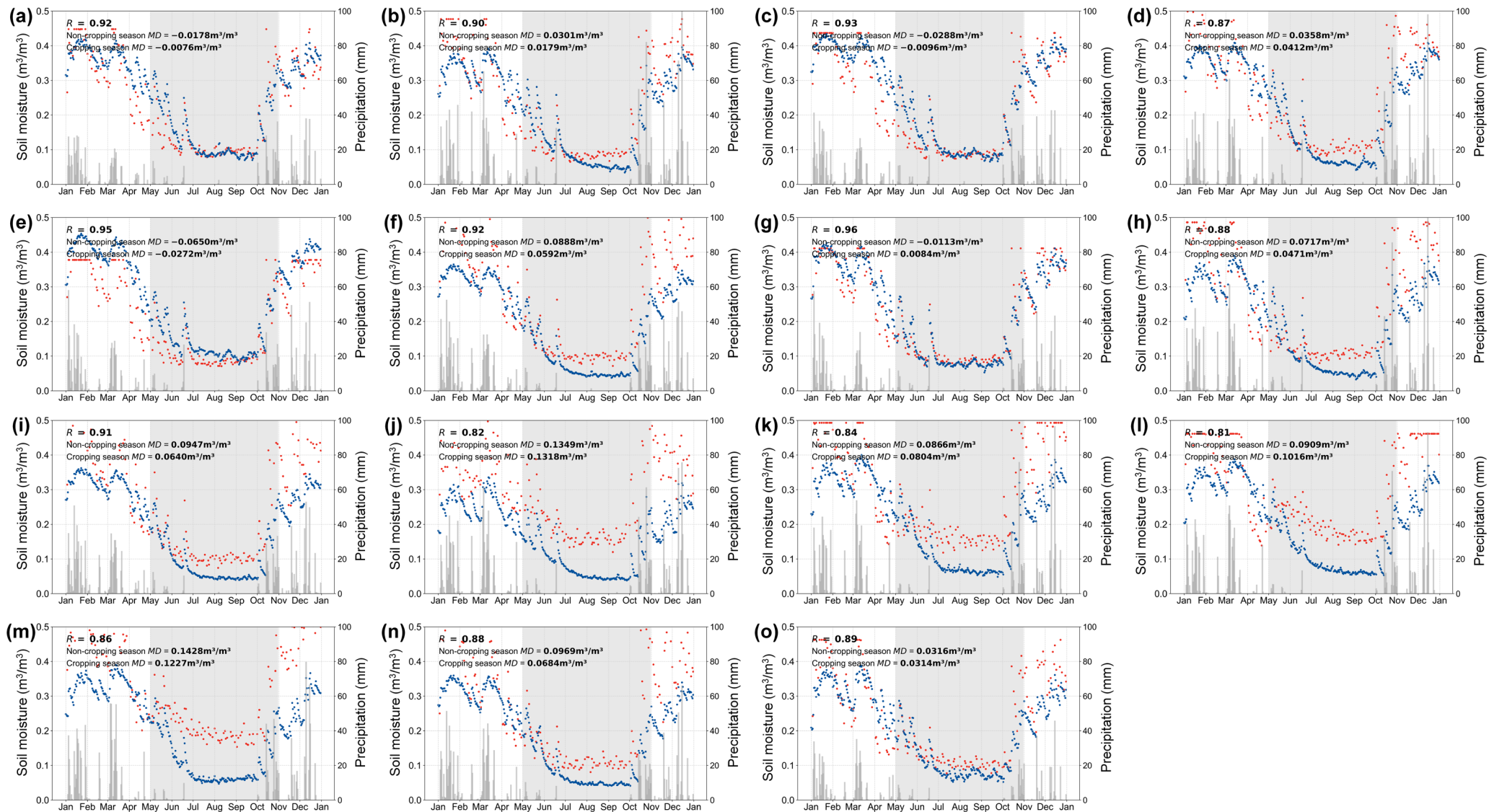
Figure S2-5. Surface soil moisture from SMAP L3_E and L4 in sampled non-irrigated grid cells in 2016. Red dots represent L3_E soil moisture and blue dots represent SMAP L4 soil moisture (left axis), and gray bars indicate precipitation (right axis). Light gray shaded area represents the cropping season. See Fig. S2-2 for grid cell locations.

S3 Sensitivity analysis of alternative irrigated and non-irrigated grid cell pairs

S3.1 10 paired grid cell locations in SJV and SV

Blue circles and lower-case letters (e.g., grid cells A, B, C) denote non-irrigated grid cells. Red circles and upper-case letters (e.g., grid cells a, b, c) represent irrigated grid cells.
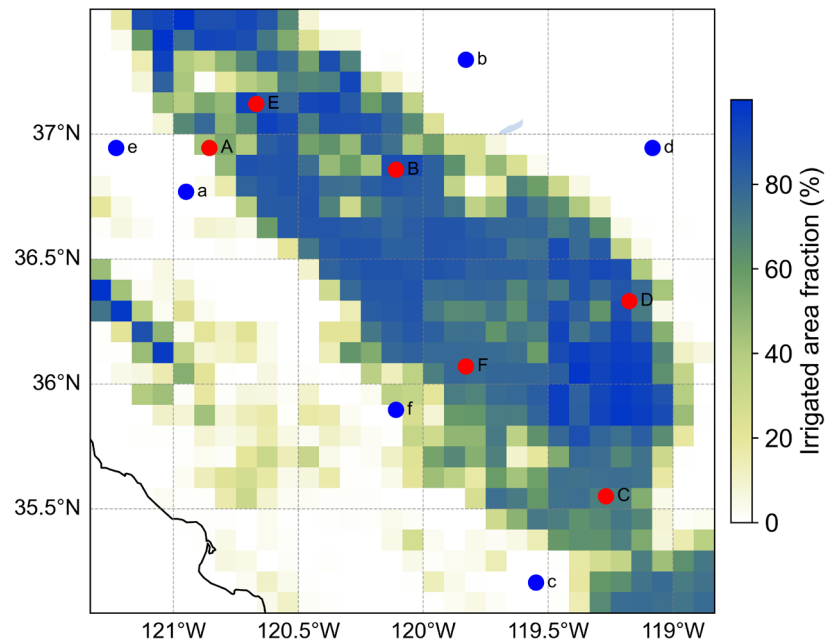
Figure S3-1. Locations of paired irrigated and non-irrigated grid cells in SJV.
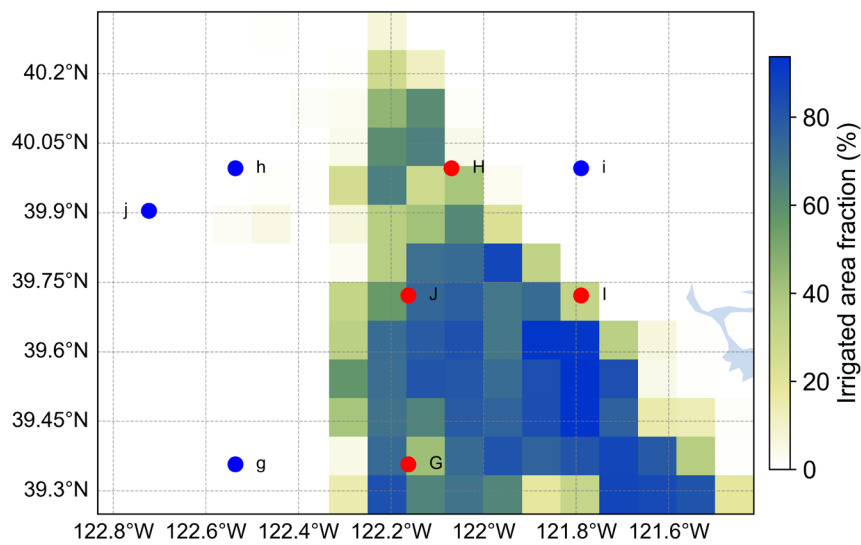
Figure S3-2. Locations of paired irrigated and non-irrigated grid cells in SV.

S3.2 Surface soil moisture of paired grid cells in SJV
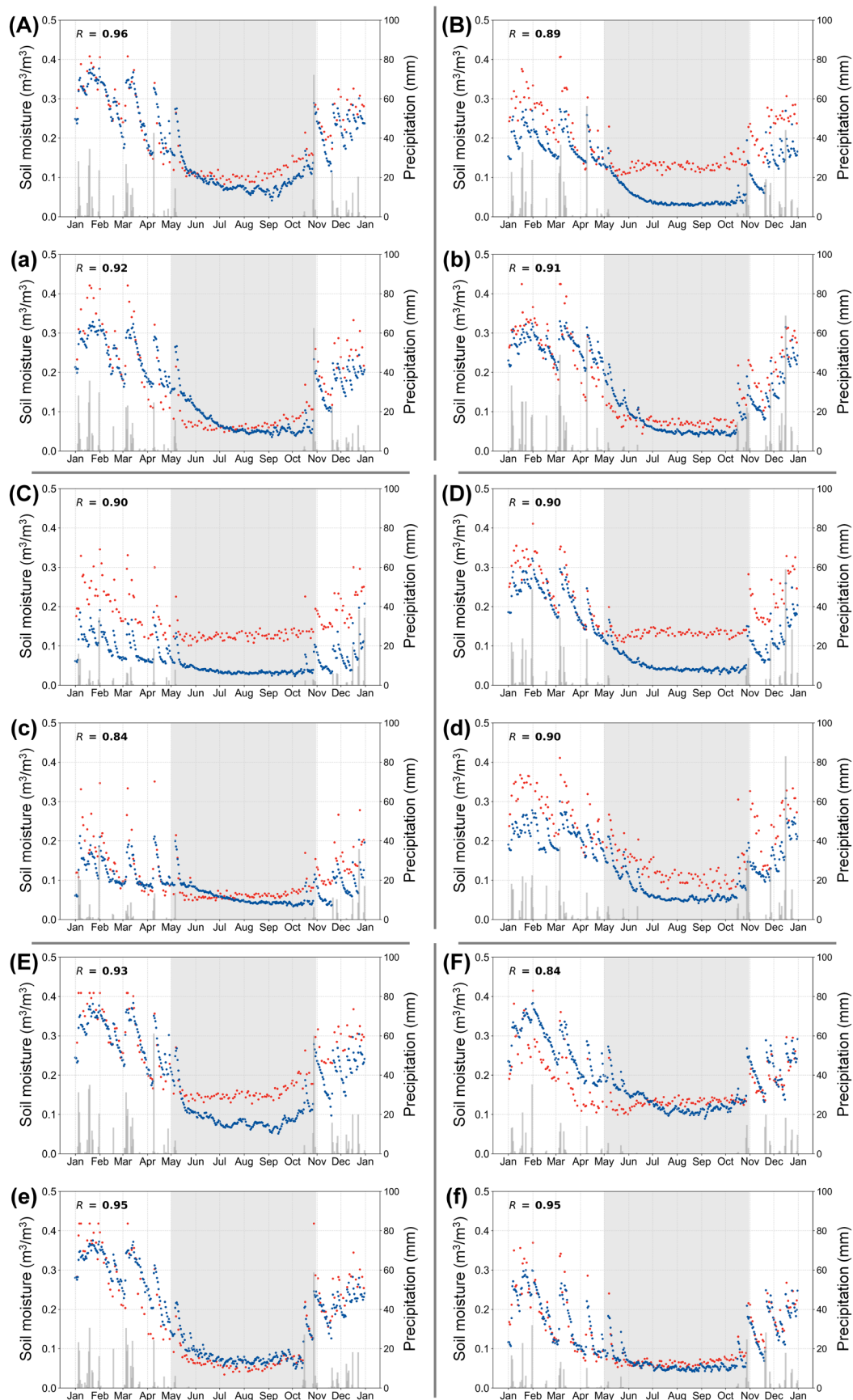
Figure S3-3. SMAP L3_E and L4 surface soil moisture of six paired grid cells in SJV, 2016. Red dots represent L3_E soil moisture and blue dots represent SMAP L4 soil moisture (left axis), and gray bars indicate precipitation (right axis). Light gray shaded area represents the cropping season. See Fig. S3-1 for grid cell locations.

S3.3 Surface soil moisture of paired grid cells in SV
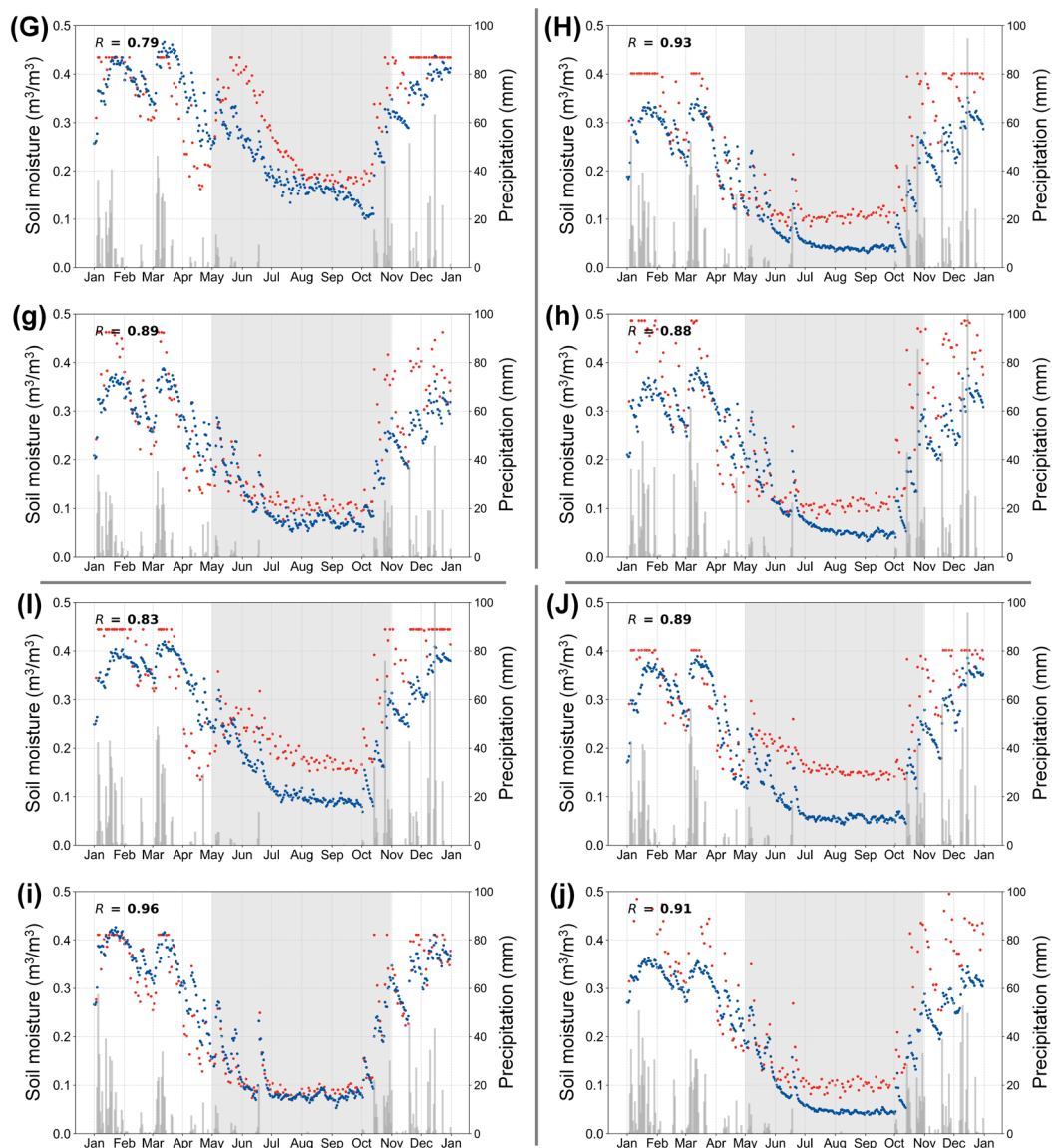
Figure S3-4. SMAP L3_E and L4 surface soil moisture of four paired grid cells in SV, 2016. Red dots represent L3_E soil moisture and blue dots represent SMAP L4 soil moisture (left axis), and gray bars indicate precipitation (right axis). Light gray shaded area represents the cropping season. See Fig. S3-2 for grid cell locations.

S4 Time series of differences between SMAP L3_E and L4 for selected grid cells

S4.1 Time series of non-irrigated grid cells in SJV and SV
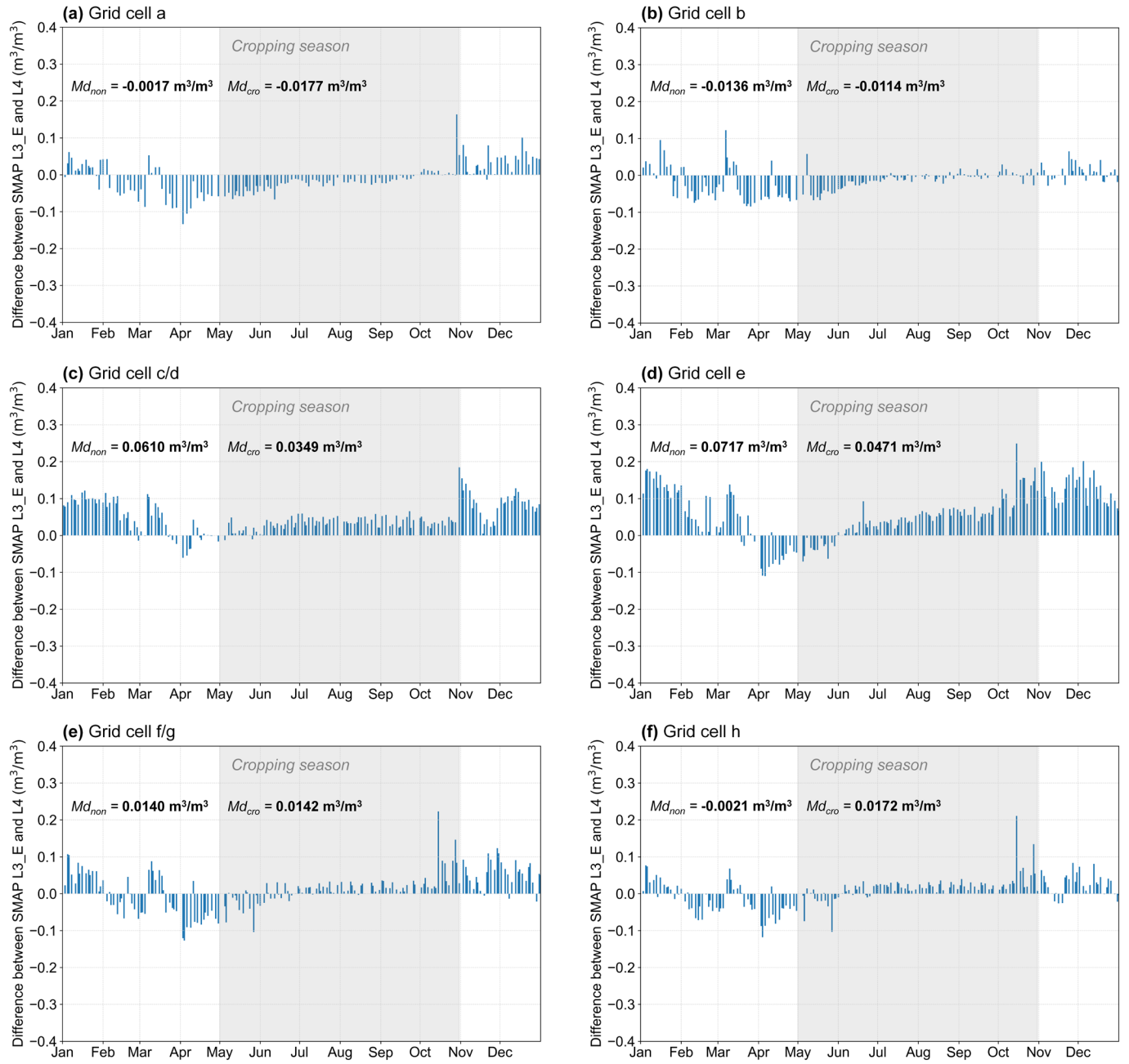
Figure S4-1. Time series of difference between SMAP L3_E and L4 for selected six non-irrigated grid cells in SJV and SV. See Fig. 1c-d for grid cell locations.

S4.2 Time series of irrigated grid cells in SJV and SV
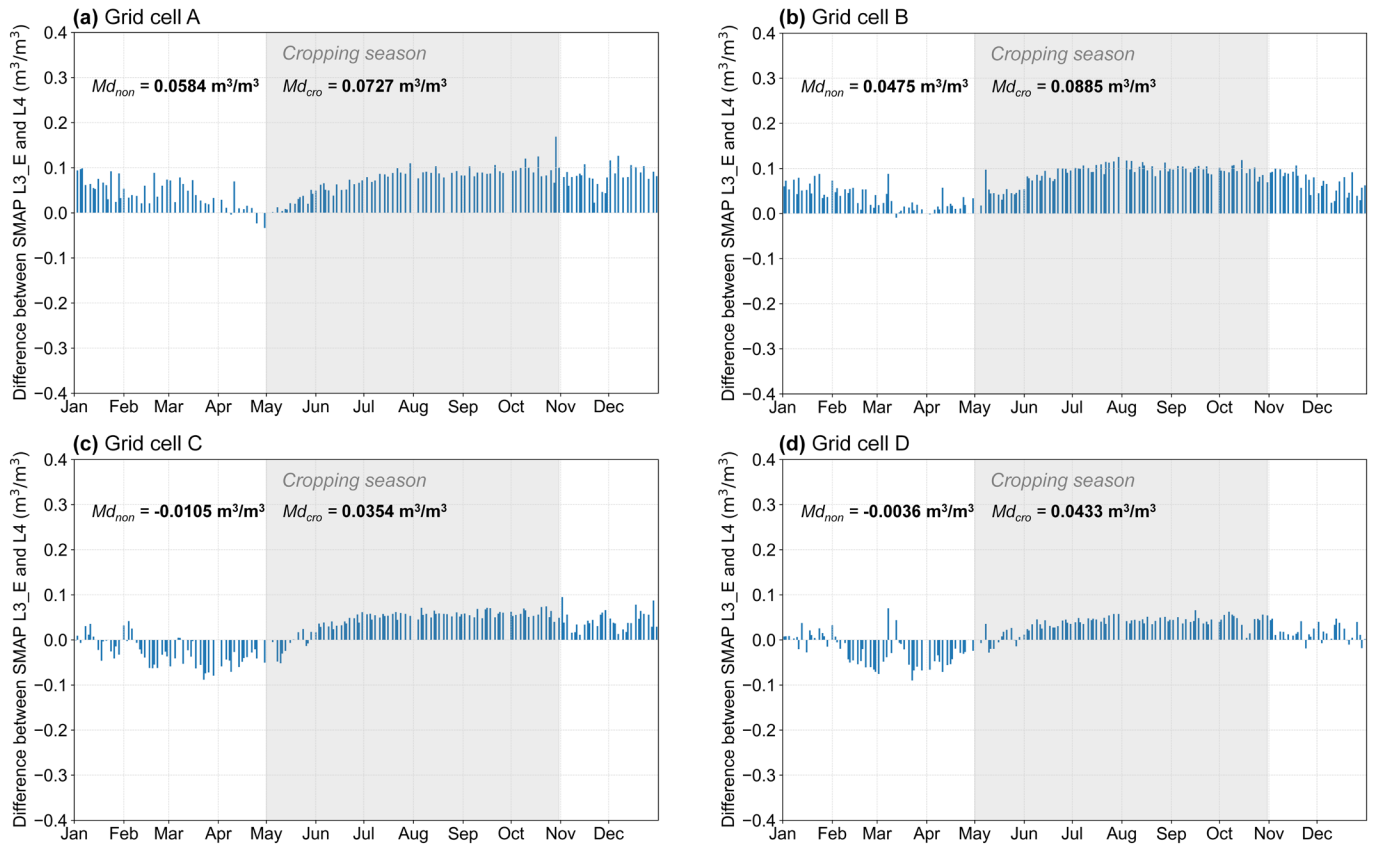
Figure S4-2. Time series of difference between SMAP L3_E and L4 for selected four irrigated grid cells in SJV. See Fig. 1d for grid cell locations.
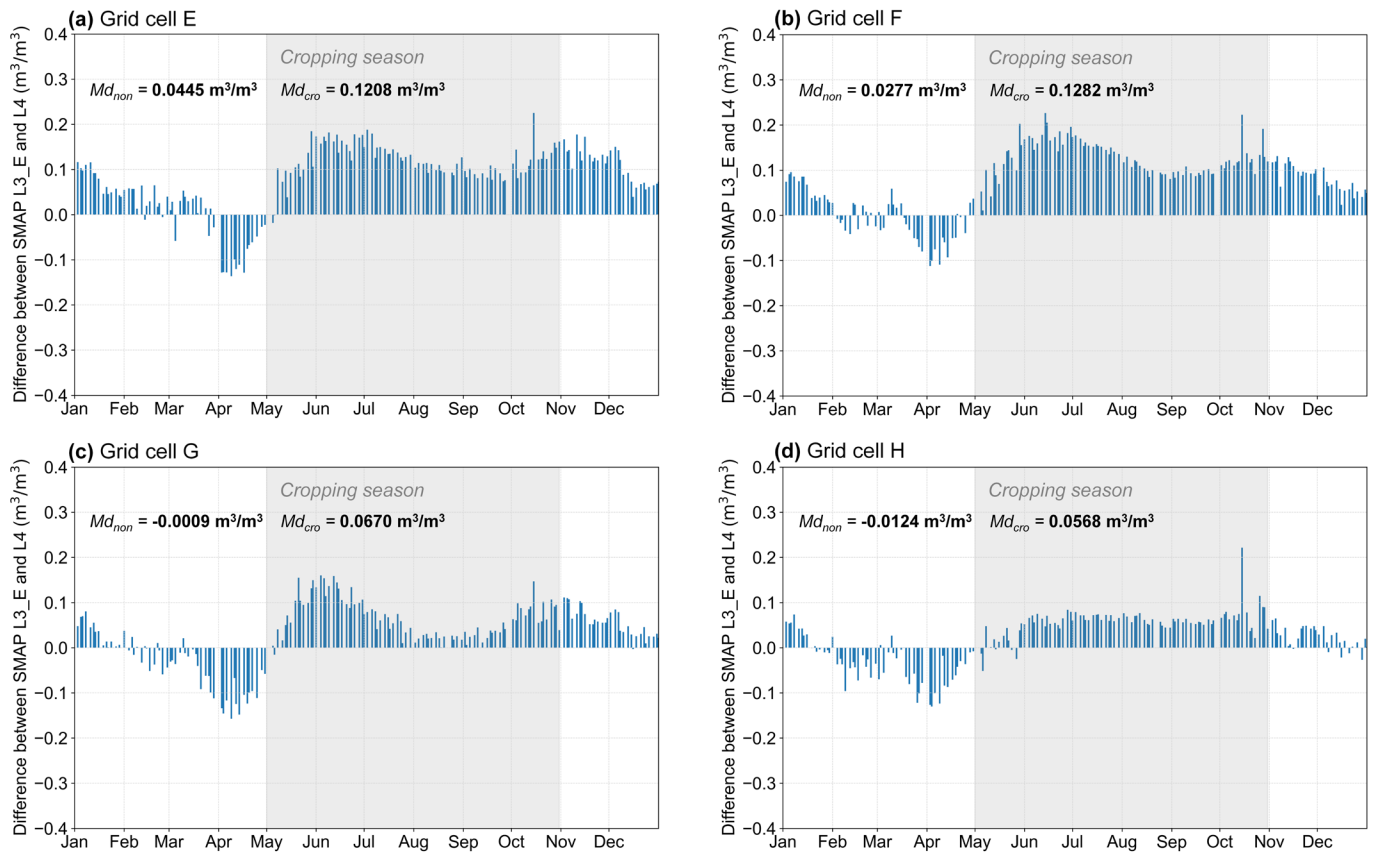
Figure S4-3. Time series of difference between SMAP L3_E and L4 for selected four irrigated grid cells in SV. See Fig. 1c for grid cell locations.

S5 Validation on consistency of temporal variability between SMAP L3_E and L4 in irrigated grid cells

S5.1 Sampling method

We sampled the irrigated grid cells for SJV and SV by the following methods:

(1) Select all irrigated grid cells that have irrigated area fraction above 20% based on the Global Map of Irrigated Area (GMIA).

(2) Select the grid cells from all irrigated grid cells from Step (1) by a uniformly subsampling method with a fixed interval (20-step interval for SJV, and 5-step interval for SV).

S5.2 Grid cell locations
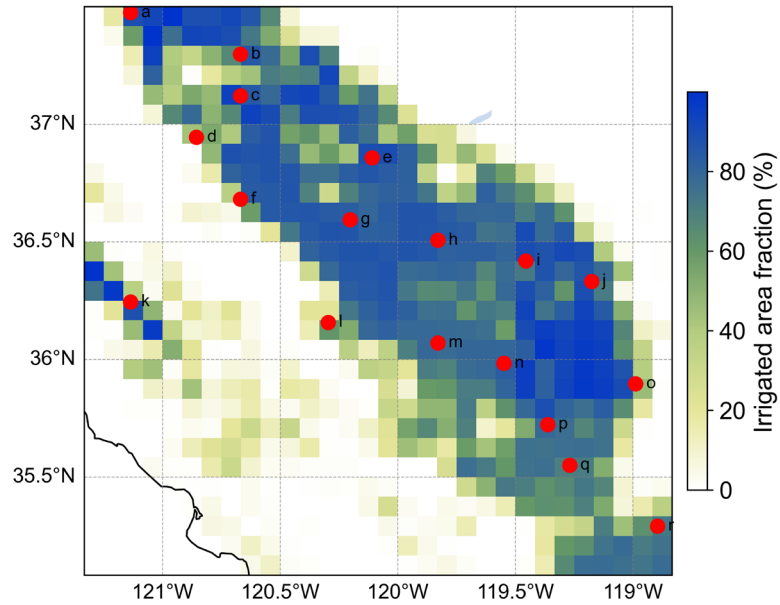
Figure S5-1. Locations of sampled irrigated grid cells in SJV (20-step interval).
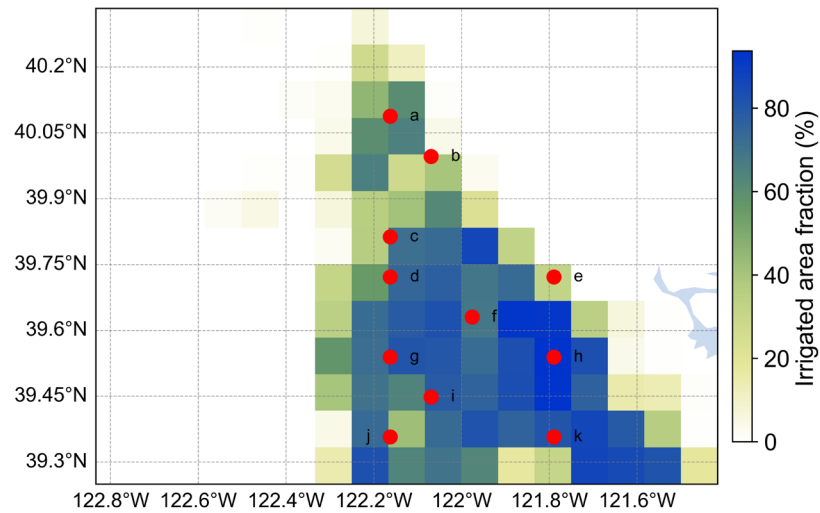
Figure S5-2. Locations of sampled irrigated grid cells in SV (5-step interval).

S5.3 Pearson Correlation Coefficient between SMAP L3_E and L4 in non-cropping season R_{non} of sampled irrigated grid cells in SJV
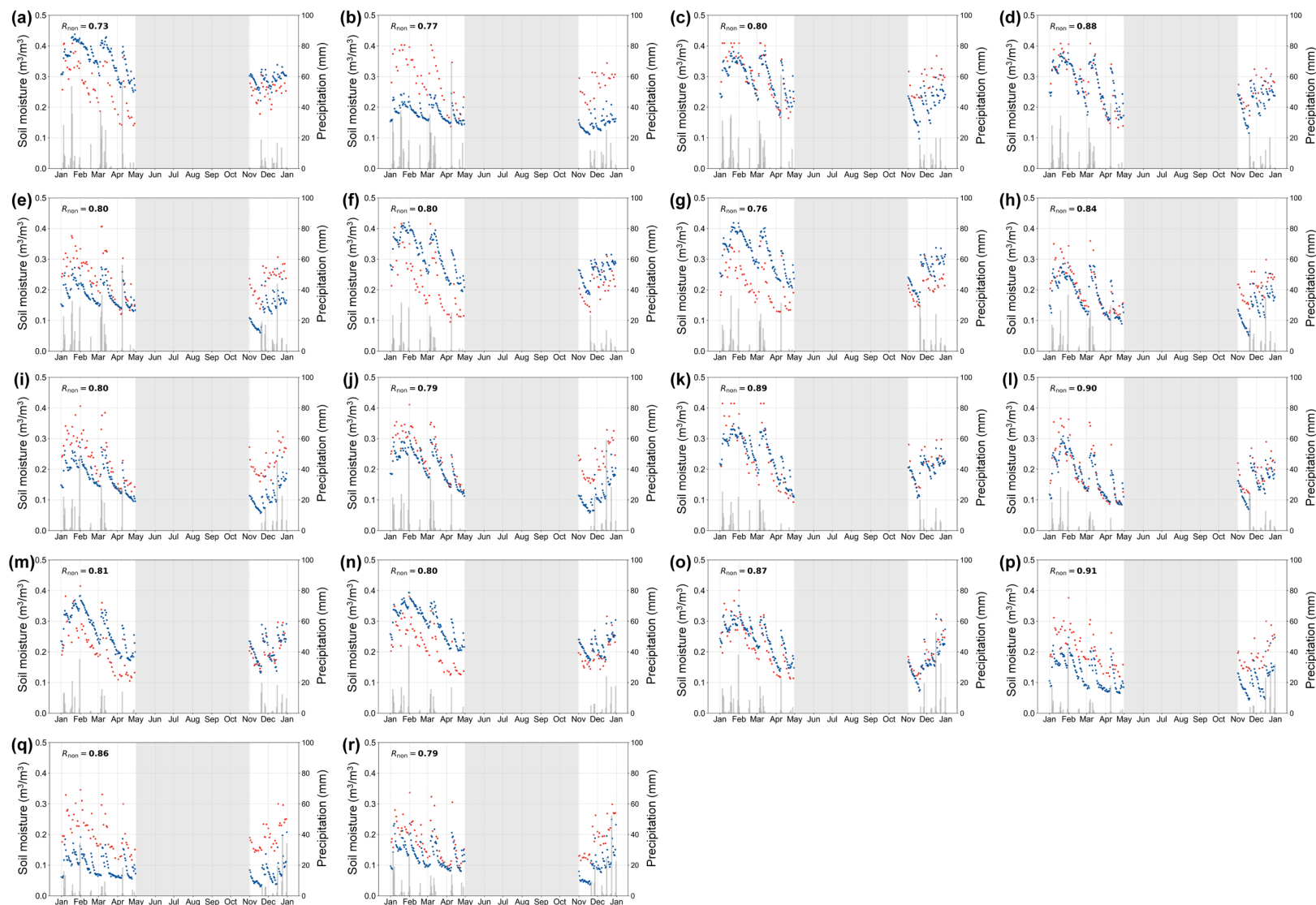
Figure S5-3. SMAP L3_E and L4 surface soil moisture and R_{non} for irrigated grid cells during the non-cropping season in SJV, 2016. Red dots represent L3_E soil moisture and blue dots represent SMAP L4 soil moisture (left axis), and gray bars indicate precipitation (right axis). Light gray shaded area represents the cropping season. See Fig. S5-1 for grid cell locations.

S5.4 Pearson Correlation Coefficient between SMAP L3_E and L4 in non-cropping season R_{non} of sampled irrigated grid cells in SV
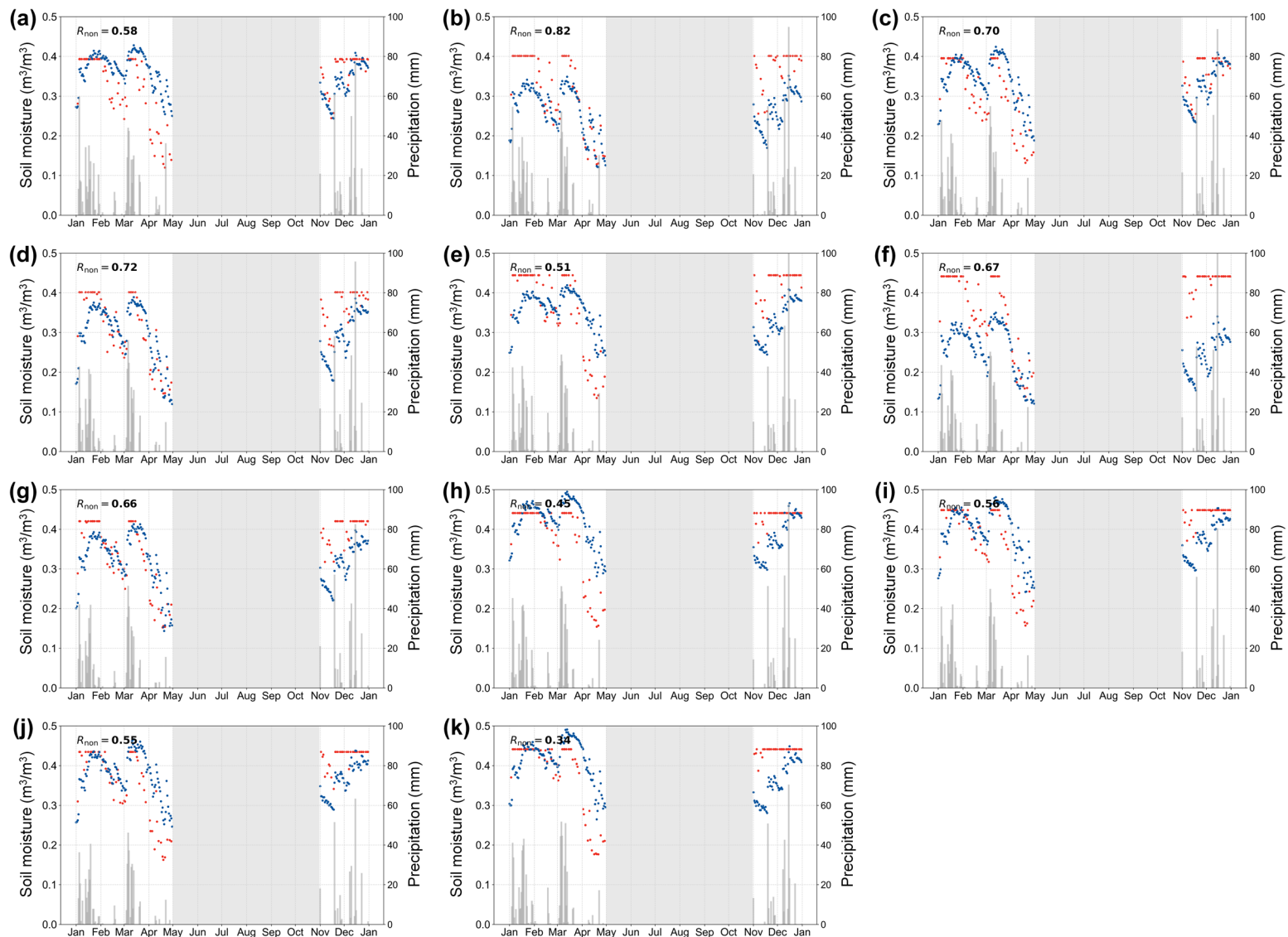
Figure S5-4. SMAP L3_E and L4 surface soil moisture and R_{non} for irrigated grid cells during the non-cropping season in SV, 2016. Red dots represent L3_E soil moisture and blue dots represent SMAP L4 soil moisture (left axis), and gray bars indicate precipitation (right axis). Light gray shaded area represents the cropping season. See Fig. S5-2 for grid cell locations.

S6 Map of SMAP's irrigation signals in SV
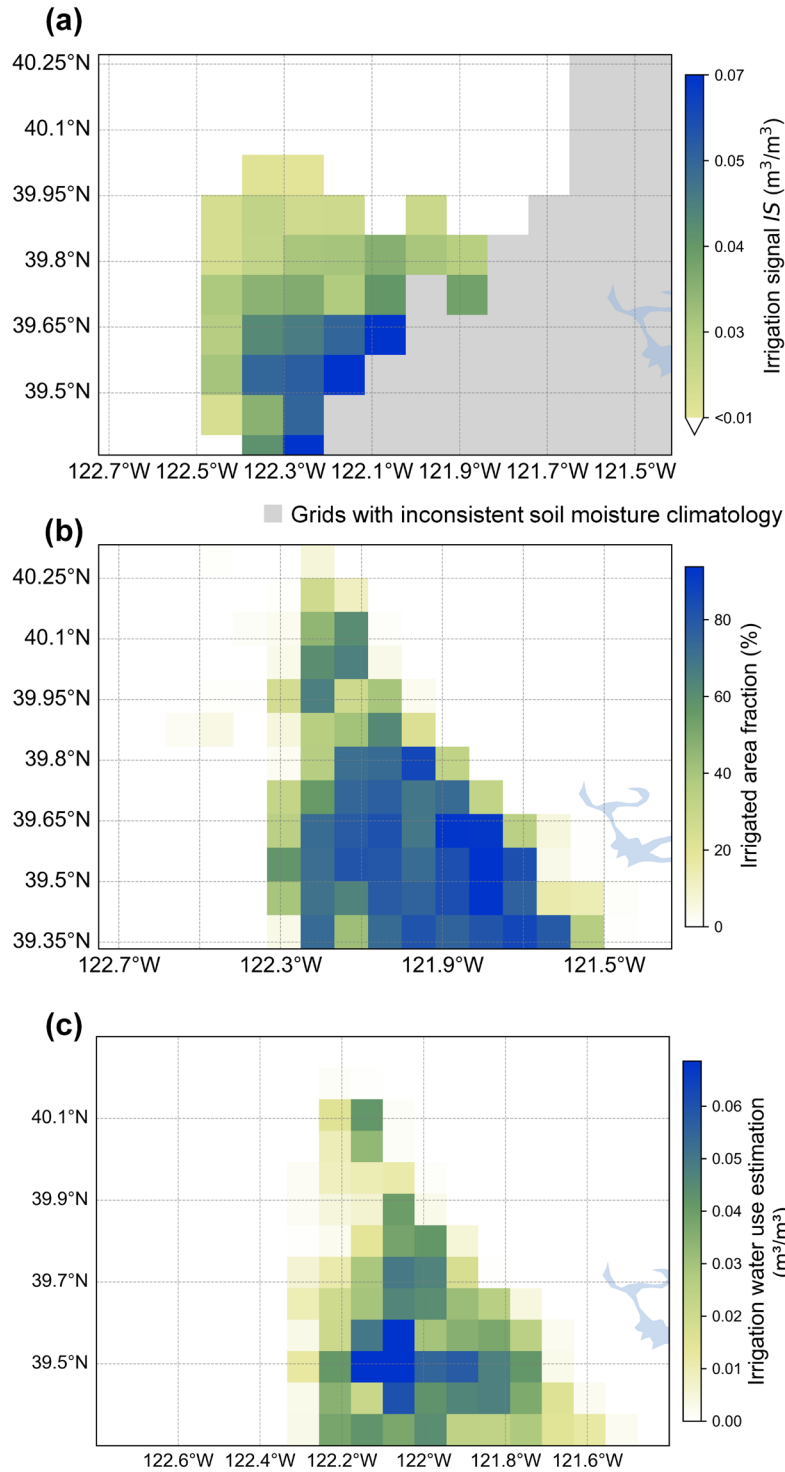
Figure S6-1. Map of irrigation signal (*IS*) and validations in SV. **(a)** Average *IS* estimated for 2016–2020. **(b)** Irrigated area fraction from the GMIA. **(c)** Average irrigation water use estimations for 2016–2020 from the ZL21 map.

Although the large area of grid cells with inconsistent soil moisture climatology limits the applicability of the proposed methods in SV (Fig. S6-1a), the remaining climatologically consistent grid cells effectively delineate the main irrigated area, particularly in the central part of the image.

S7 Elevation map for Central Valley, California
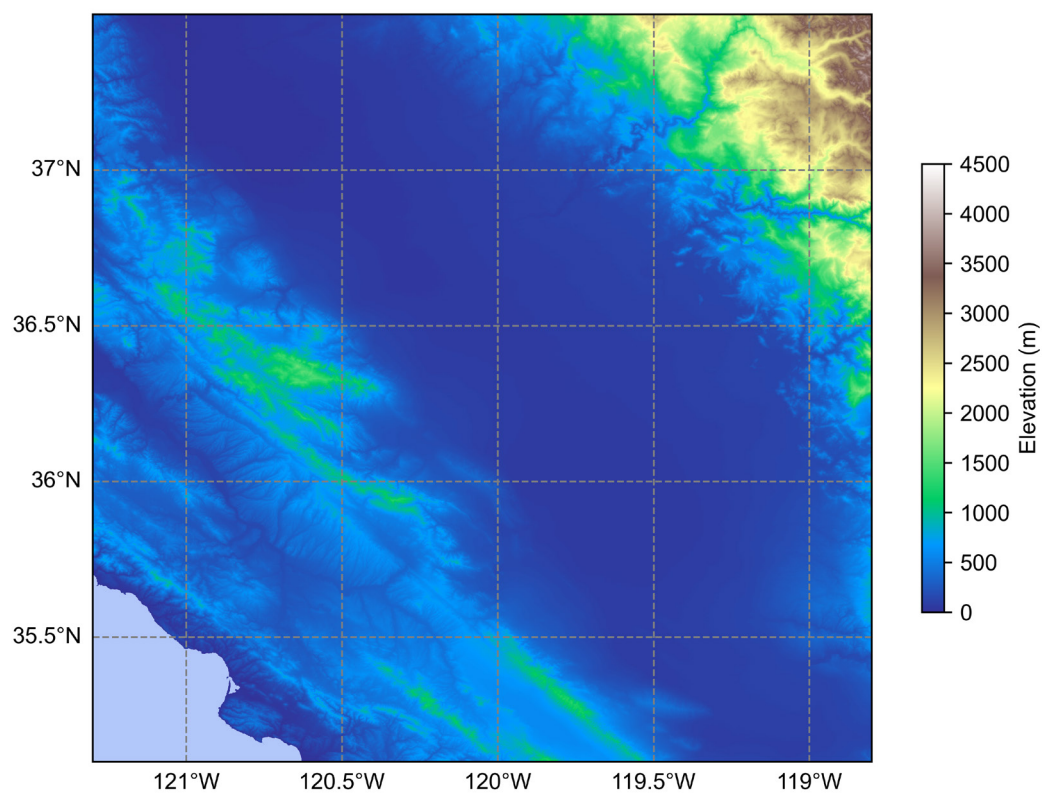
Figure S7-1. Elevation map for SJV.
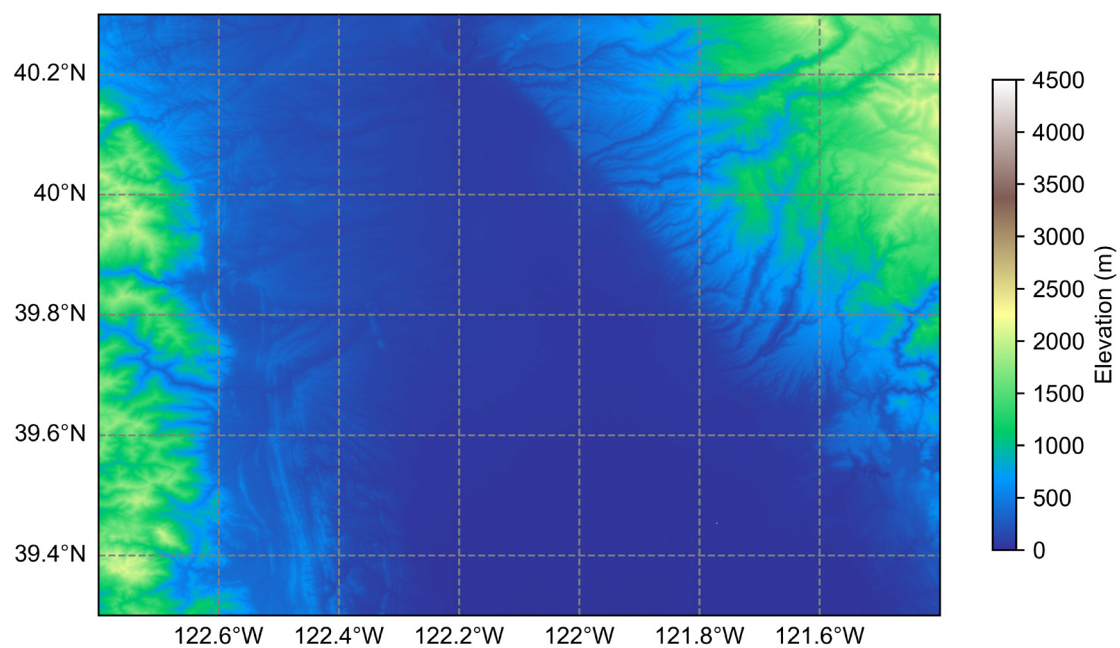
Figure S7-2. Elevation map for SV.

S8 Scatterplots of comparison between the *IS* map and two benchmark maps under different thresholds of variability judging Correlation Coefficient *R* values
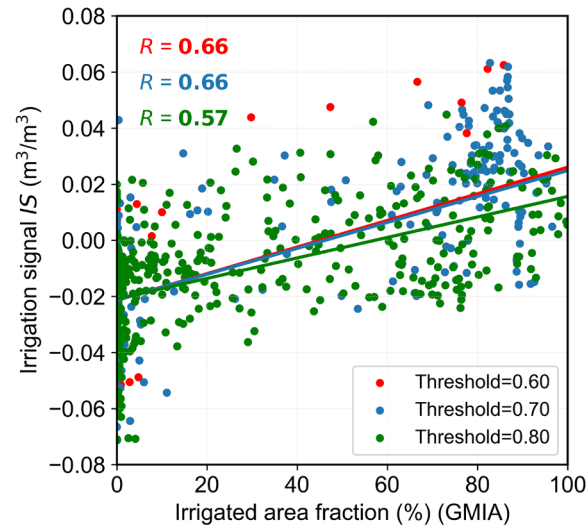
Figure S8-1. Scatterplot of grid cell values in the IS map compared with irrigated area fraction (GMIA).
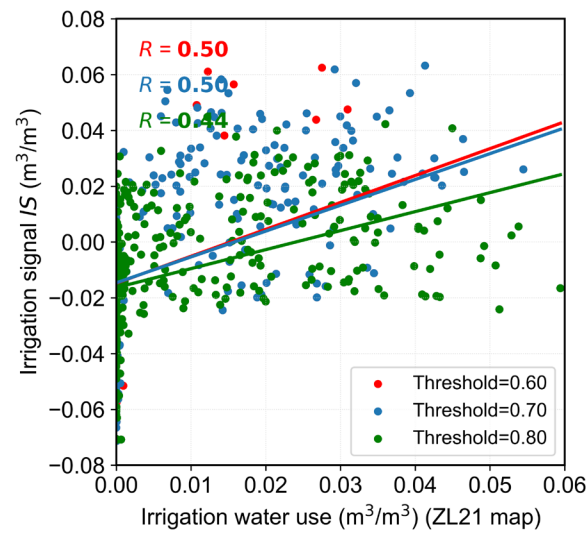
Figure S8-2. Scatterplot of grid cell values in the IS map compared with the irrigation water use (ZL21 map).

S9 © Google Earth image showing intensive urbanization in region (iii), SJV
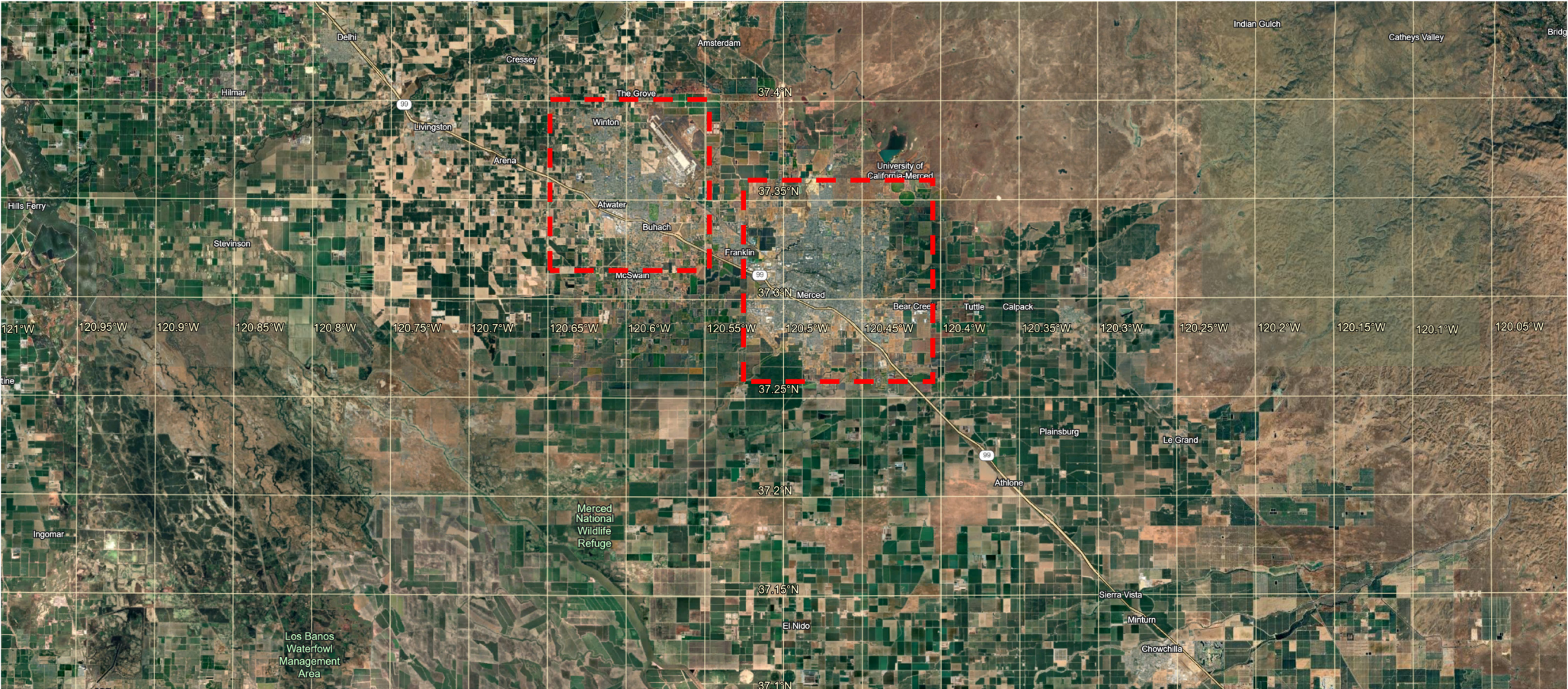
Figure S9-1. Intensive urbanization in region (iii) as observed from Google Earth imagery. See Fig. 7a for location of region (iii) within SJV.

S10 Map of SMAP's irrigation signals in Snake River Basin (SRP)and Nebraska High Plain (NHP)

S10.1 Geographical locations and irrigated area fractions (GMIA) for SRP and NHP
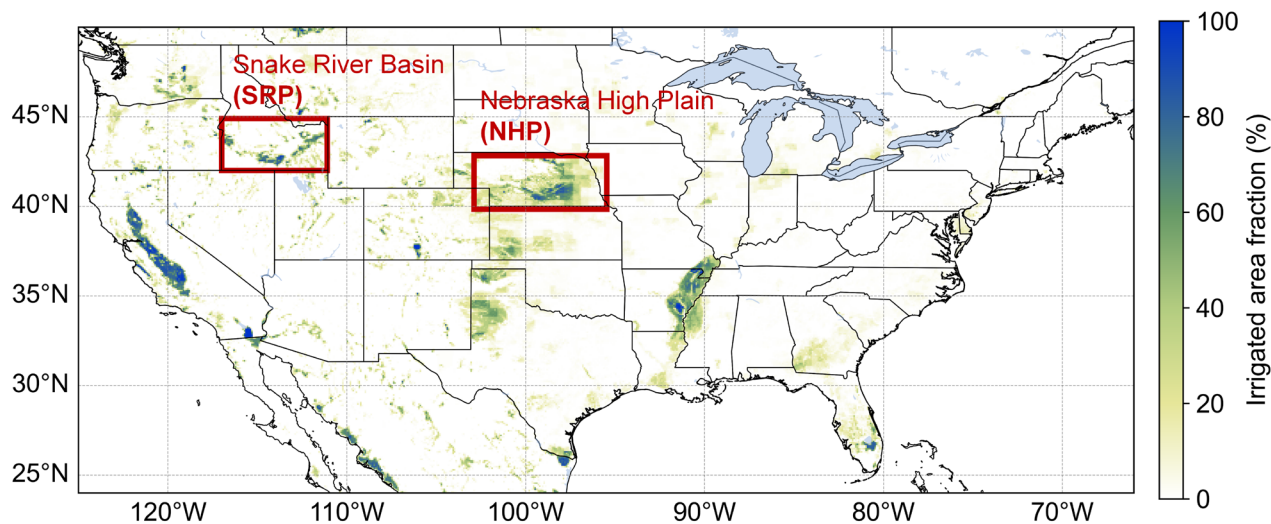
Figure S10-1. Geographical locations and irrigated area (GMIA) fractions for SRP and NHP.

S10.2 Map for SRP
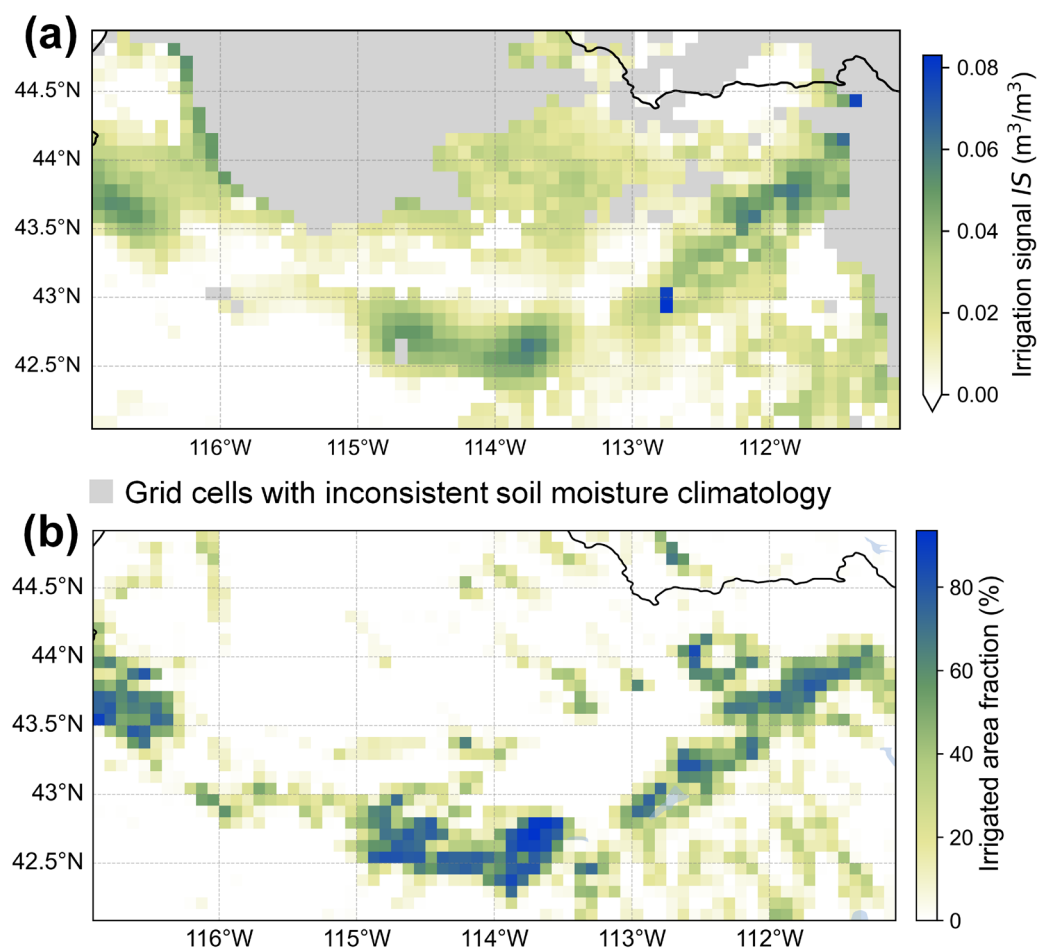
Figure S10-2. Map of Average irrigation signals (*IS*) estimated for 2016–2020 and irrigated area fraction from the GMIA in SRP. (a) Average irrigation signals (*IS*) and (b) Irrigated area fraction.
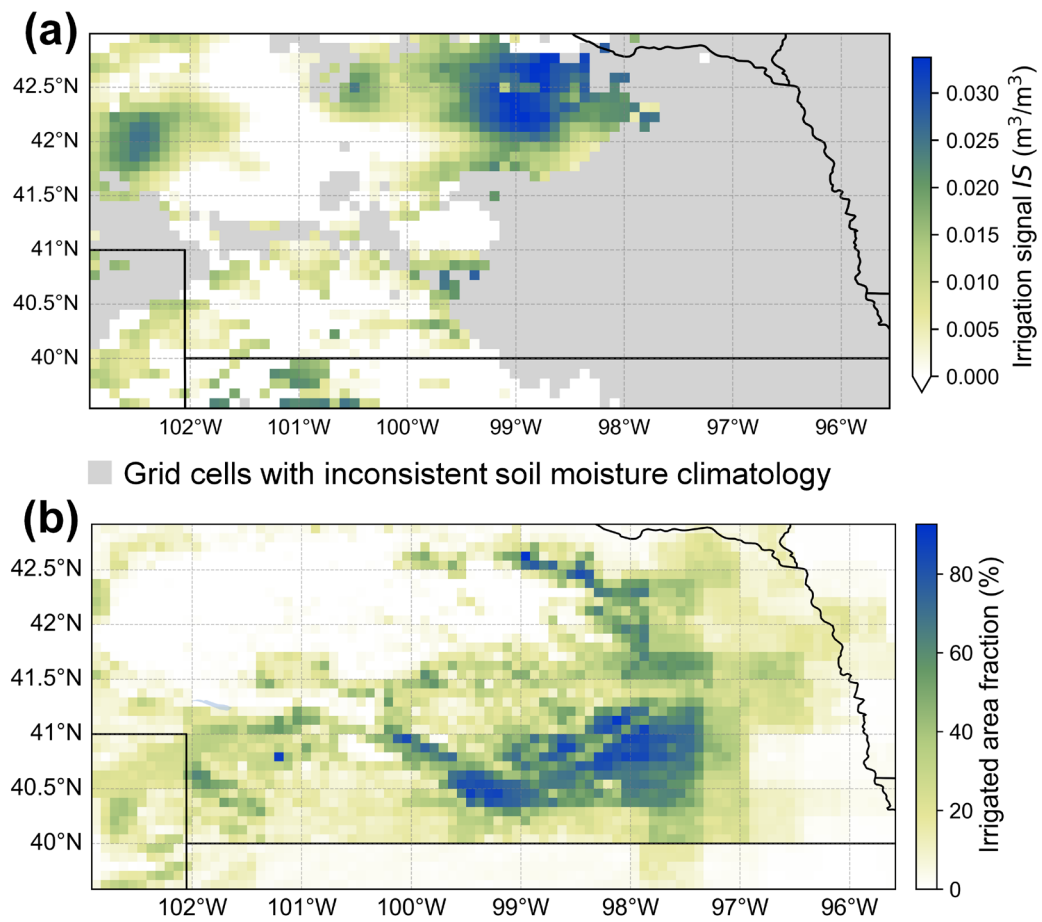
Figure S10-3. Map of Average irrigation signals (*IS*) estimated for 2016–2020 and irrigated area fraction from the GMIA in NHP. (a) Average irrigation signals (*IS*) and (b) Irrigated area fraction.