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Soil moisture estimation in South Asia via assimilation of SMAP retrievals

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S1: Comparison of SMAP soil moisture with in-situ measurements

Table S1 includes the metrics computed for the SMAP soil moisture retrievals and the modeled (OL and DA-NoCDF) soil moisture estimates by comparing them with in-situ data from 2015 onwards. Only 30 grid cells have both in-situ measurements and SMAP soil moisture retrievals available. The SMAP soil moisture statistics are based on observations available on any day between 2015-2020, i.e., there are many temporal gaps in the SMAP soil moisture timeseries. However, the OL and DA-NoCDF statistics are computed from daily estimates. (Note: The statistics included in Table 2 of the manuscript take into account all 78 grid cells suitable for comparison with the modeled estimates, which do not have any data gaps.)

SMAP soil moisture retrievals and DA-NoCDF (IMERG) yield the lowest mean bias and RMSE. However, the SMAP retrievals have the largest mean relative RMSE. Consistent with contemporary literature, the raw SMAP retrievals show the highest correlation with in-situ measurements. Important to note is the improvement in all statistics after assimilation as compared to the OL.

Table S1. Statistics of OL and DA-NoCDF soil moisture estimates (2015 to 2020) computed with respect to the soil moisture measurements across the Tibetan Plateau. Mean refers to the average of all the stations included within the network. OL = Open Loop and DA-NoCDF = data assimilated estimates without CDF matching of the SMAP retrievals.

Tibetan Plateau		**MERRA2**		**IMERG**	
Statistic	SMAP soil moisture	**OL**	**DA-NoCDF**	**OL**	**DA-NoCDF**
Mean bias m^3 m^{-3}	0.02	0.07	0.06	0.03	0.02
Mean RMSE m^3 m^{-3}	0.10	0.13	0.12	0.11	0.10
Mean relative RMSE [-]	2.00	1.87	1.79	1.51	1.48
Mean correlation	0.48	0.30	0.37	0.33	0.45

S2: Anomaly-scaled retrieval assimilation

Assimilation using an anomaly-based approach (DA-Anom.) was also tested. In this approach, the retrieval mean was mapped to the land surface model mean and updates were computed using the resultant anomalies such that:

$$\text{Observation anomaly}(s,t) = \text{SMAP soil moisture}(s,t) - \text{Mean SMAP moisture}(s) \tag{S1}$$

$$\text{Observed value}(s,t) = \text{Mean NoahMP soil moisture}(s) + \text{Observation anomaly}(s,t) \tag{S2}$$

where, *s*= location in space and *t*= instance in time. Figure S1 shows a sample timeseries for a location that is 80% irrigation-equipped. It is apparent that assimilation estimates (DA-CDF) after anomaly scaling closely mimic the OL estimated soil moisture throughout the year whereas DA-NoCDF is able to update the soil moisture based on the information in the SMAP observations, particularly during the winter months.

Figure S2 presents the differences between OL versus DA estimated soil moisture for the two main seasons. DA-CDF (subplots (a) and (e)) and DA-Anom. (subplots (b) and (f)) simulations show some spatial similarities during both seasons. During summer, the DA-Anom. simulations (Fig. S2(b)) do not show any visible updates across the Indus, Ganges, and Brahmaputra basins. This signal is, however, apparent in the DA-NoCDF map (Fig. S2(c)). For winter, the DA-Anom. estimates (Fig. S2(f)) show positive updates across the Ganges Basin, however, little influence is seen across the Indus and Brahmaputra basins.

Figure S2(d) presents the annual mean differences between the OL and DA-Anomaly runs. Positive differences are observed across the Tibetan Plateau, similar to the DA-CDF run (Fig. 4). The statistics show that DA-CDF estimates have the lowest accuracy across the Tibetan Plateau (lower than the OL). The performance of the individual runs could be further explored if in-situ measurements were available across the lower part of the study domain. Unfortunately, there are no publicly available soil moisture datasets across the three primary river basins in South Asia, i.e., Indus, Ganges, and Brahmaputra, from 2015 onwards.

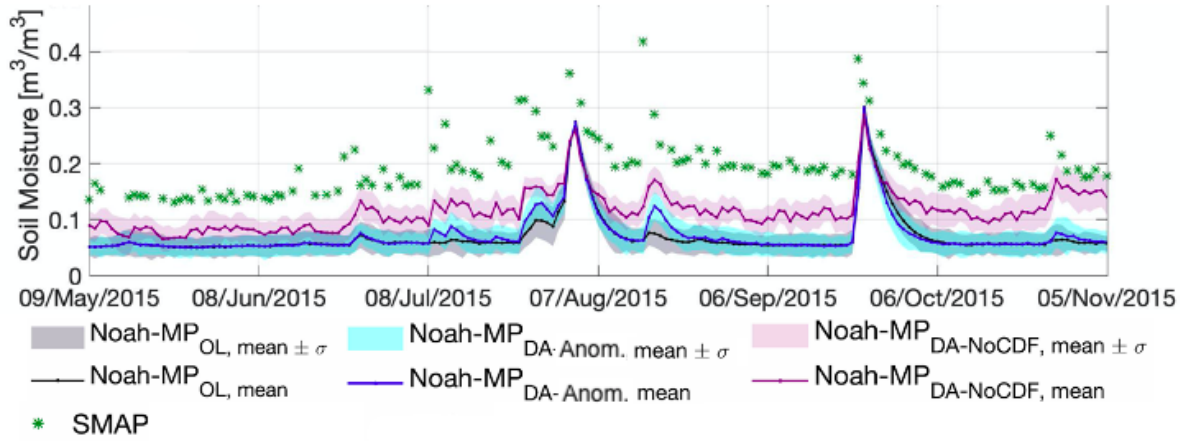

Figure S1. Comparative timeseries of OL and DA estimated surface (top 5 cm) soil moisture at an irrigation-equipped pixel. The solid line represents the ensemble mean whereas the shaded areas represent mean +/- standard deviation across the full ensemble. DA-CDF: anomaly-based assimilation; DA-NoCDF: no CDF-matching based assimilation.

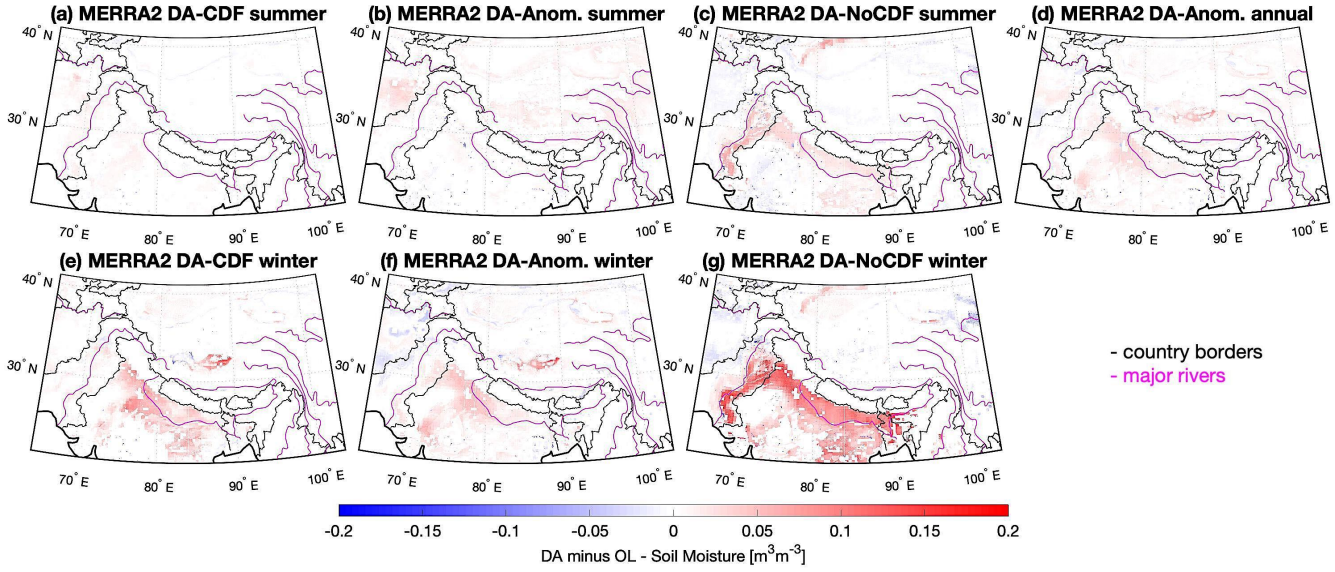

Figure S2. Differences between the mean soil moisture estimated by the OL and DA simulations during the summer (April 2016 to September 2016) versus the winter months (October 2015 to March 2016). DA-CDF= assimilation of CDF-matched SMAP retrievals; DA-Anom.= assimilation of anomaly scaled SMAP retrievals; DA-NoCDF= no CDF-matching of SMAP retrievals.