Global AMSR2 Soil Moisture Downscaling using Gap-filled LST data

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Background

- Remote sensing technique has been providing SM retrievals on a range of spatial/temporal scales. The satellite observations from passive microwave sensors can be converted from brightness temperatures (T_B) to SM retrievals by SCA algorithm.
- Passive microwave SM products have restricted spatial resolution of tens of kilometers
  - Great spatial mismatches between in-situ measurements and remotely sensed SM retrievals
  - Not enough for many hydrological or agricultural related applications at a finer scale.

Background

- AMSR2/GCOM-W1 surface soil moisture (LPRM) L3 1 day 10 km x 10 km descending V001 is a Level 3 (gridded) data set. It is derived from passive microwave remote sensing data from the Advanced Microwave Scanning Radiometer 2 (AMSR2), using the Land Parameter Retrieval Model (LPRM). There are two products per day, one ascending (daytime) and one descending (nighttime). The data covers the period from May 2012, when the JAXA Global Change Observation Mission-1st Water GCOM-W1 satellite was launched, to the present.

- The LPRM (Land Parameter Retrieval Model) is based on a forward radiative transfer model to retrieve surface soil moisture and vegetation optical depth. A unique feature of this method is that it can be applied at any microwave frequency, making it very suitable to exploit all the available passive microwave data from various satellites.

Source: https://disc.gsfc.nasa.gov/datasets/LPRM_AMSR2_DS_D_SOILM3_V001/summary

Methodology

- The relationship between the GLDAS derived θ and ΔT_s is

$$\theta(i,j) = a_0 + a_1 \Delta T_s(i,j)$$

- The 1 km θ calculated from $\theta - \Delta T_s$ model needs to be adjusted by 10 km AMSR2 Θ, because:
  - AMSR2 10 km Θ are retrieved from microwave radiometer C-band T_B, while model outputs are calculated from MODIS LST derived from spectroradiometer VIS/IR band observations.
  - Microwave radiometer represents SM at 0 - 5 cm layer, while the model outputs are calculated from MODIS LST representing a few mm from the surface.

- AMSR2 10 km morning / evening overpasses Θ were corrected using difference between AMSR2 10 km θ and average of 1 km model outputs θ corresponding to that 10 km grid, as

$$\theta^c(i,j) = \theta(i,j) + [\Theta - \frac{1}{n}\sum \theta_n]$$

Gap-filling Method

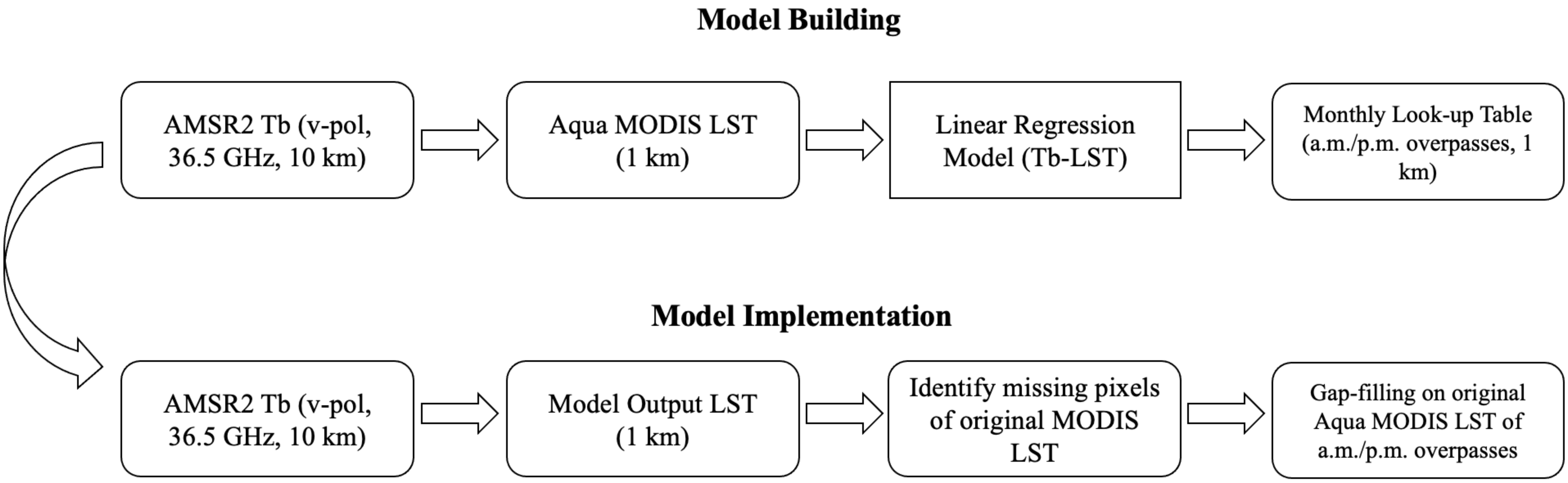
- The relationship between AMSR2 Tb (36.5GHz at V-pol) and MODIS LST can be modeled by a linear regression equation (Parinussa et al., 2016), as:

$$LST_G = slope * Tb_{,36.5v} + offset$$

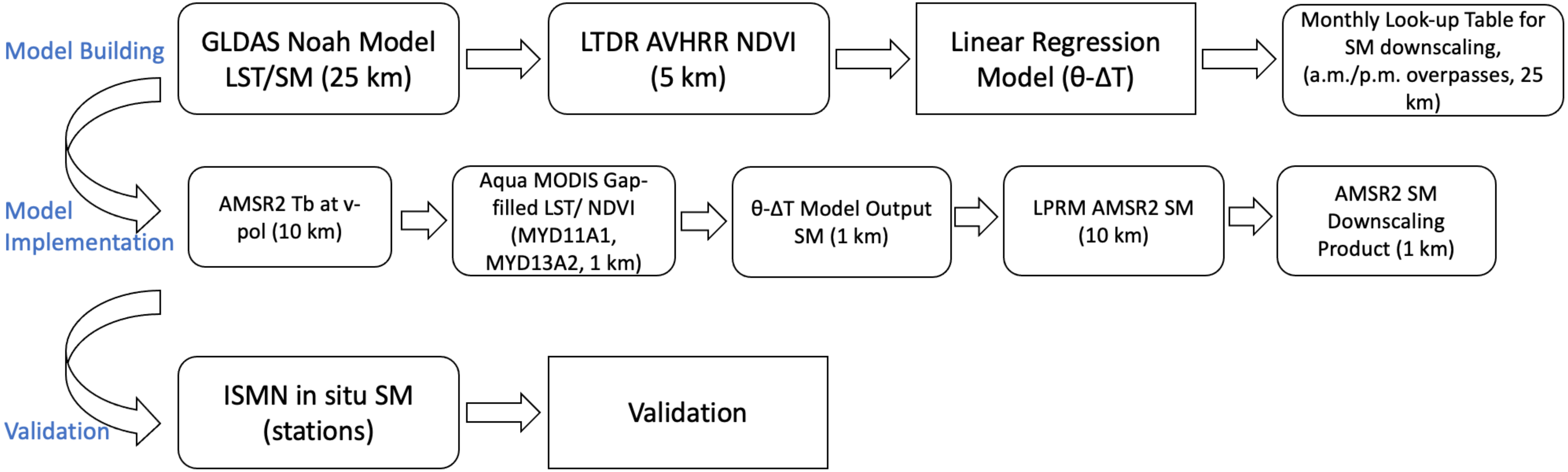
- The AMSR2 Tb-MODIS LST relationship was modeled by each AMSR2 pixel at 10 km resolution, using all available AMSR2/MODIS pixels in 2015-2020. An assumption was made that the linear regression equation can be applied to all the 1 km MODIS pixels within the corresponding AMSR2 pixel domain. The pixels based slope and offset were used to scale AMSR2 Tb observations into the MODIS LST product.

- Each individual pixel in time was assessed and gaps in the MODIS LST product that were caused by clouds or aerosols, once AMSR2 observations were available, filled through the pixels based linear regression.

Workflow for LST Gap-filling



Workflow for AMSR2 SM Downscaling

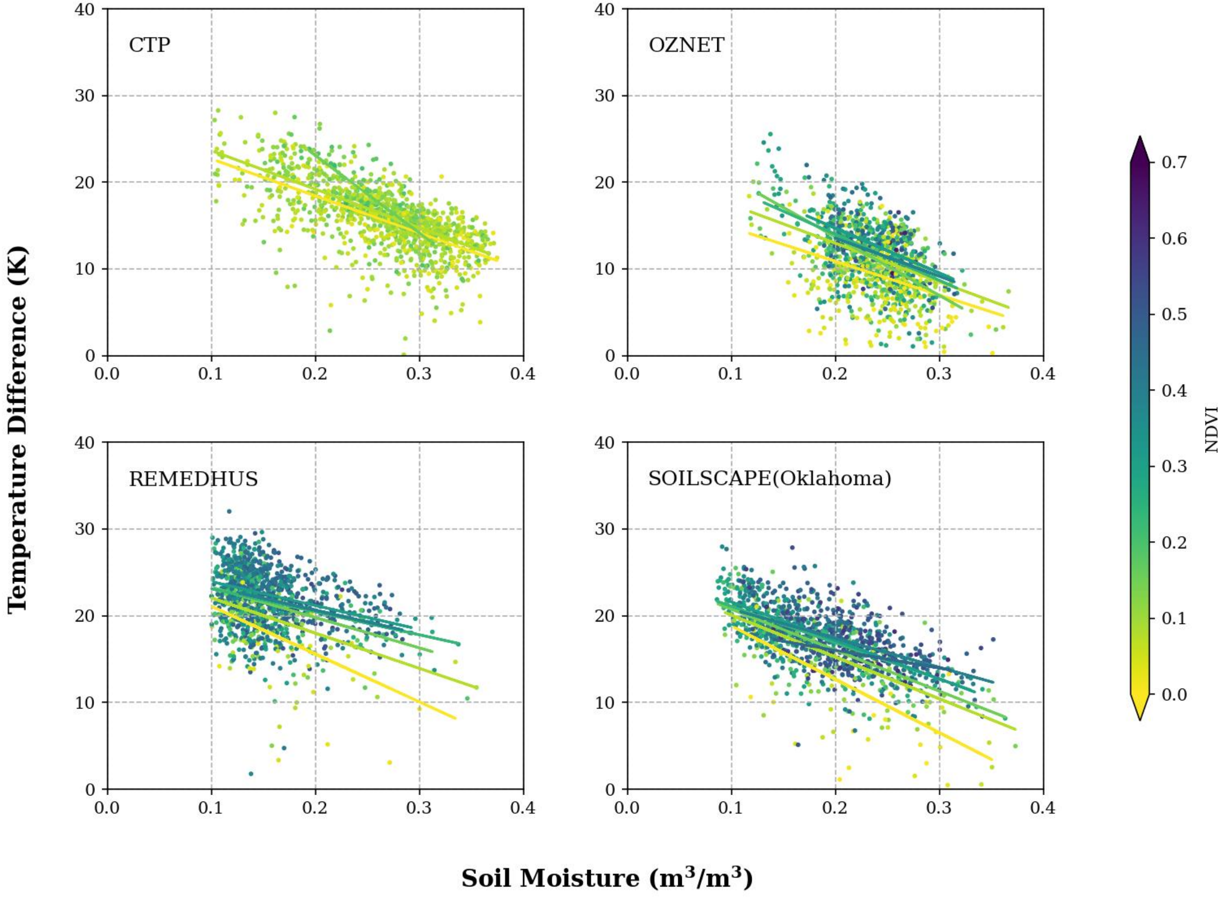


DATA SETS

- GLDAS (Global Land Data Assimilation System) Noah Land Surface Model 0.25-degree (25 km) L4 3-hourly V02 (1981-2018)
  - Soil moisture: (0-10 cm layer)
  - Surface skin temperature
- LTDR (Land Long Term Data Record V05, 5 km)
  - NDVI: AVHRR (Advanced Very High-Resolution Radiometer) (NOAA satellites N07-N19)
  - Aggregated to GLDAS grid scale using IDW (Inversed Distance Weighting) method.
- Aqua MODIS V06 (1 km)
  - Daily LST (MYD11A1)
  - Biweekly NDVI (MYD13A2)
- AMSR2 Brightness Temperature (v-pol, 36.5 GHz)
- AMSR2/GCOM-W1 surface soil moisture (LPRM) L3 1 day 10 km x 10 km descending V001
- GPM (Global Precipitation Measurement) – IMERG (Integrated Multi-satellite Retrievals for GPM) 0.1-degree (10 km) L3 daily Precipitation V03
- ISMN (International Soil Moisture Network)
  - Measurements are at the 0.01 m soil layer.

$\theta - \Delta T_s$ model derived from the GLDAS Noah model output from 1981-2018

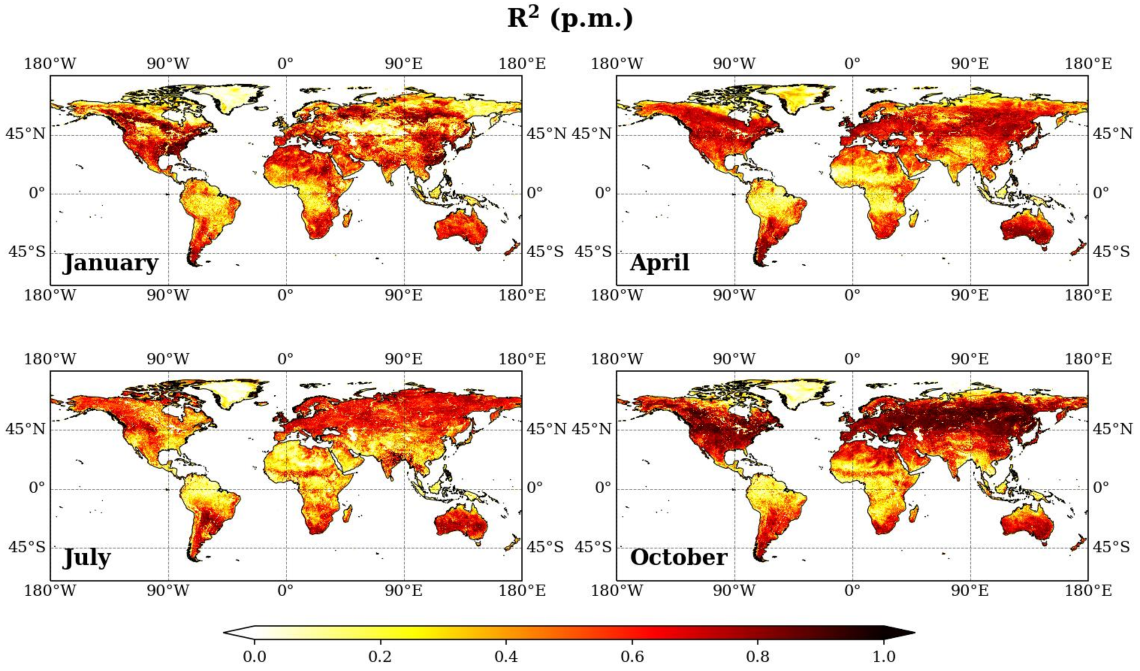
$\theta - \Delta T_s$ MODEL EVALUATION

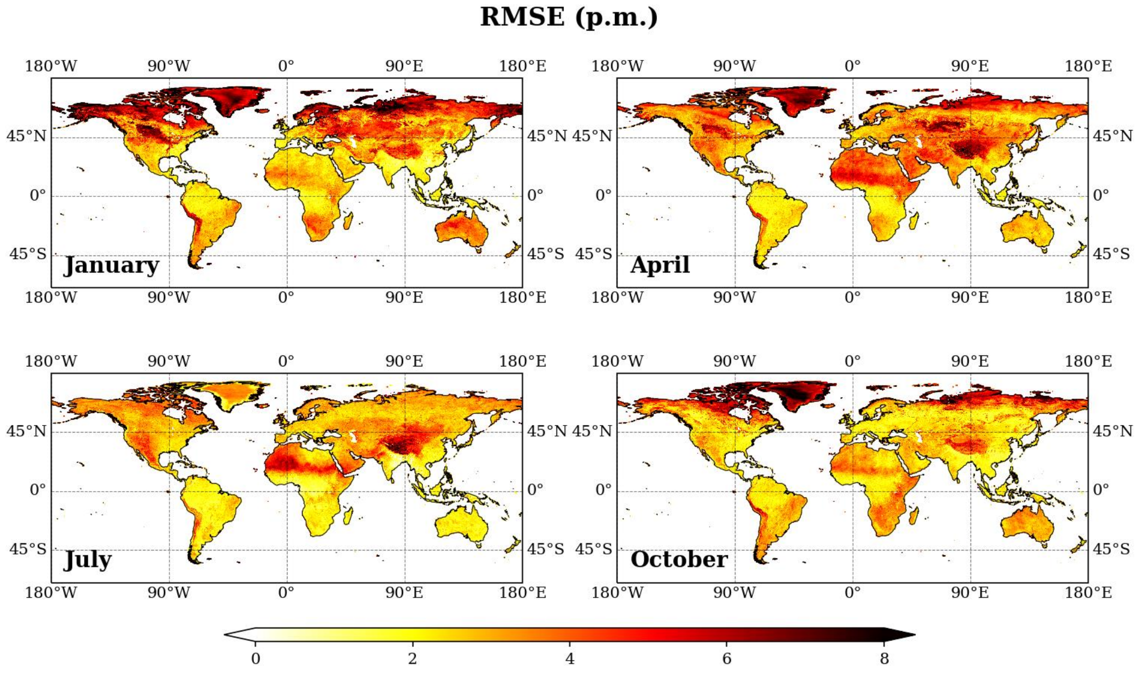


SM Network	NDVI Class						
	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7
CTP	0.424	0.436	0.81	-	-	-	-
OzNet	0.158	0.254	0.352	0.221	0.230	0.218	-
REMEDHUS	0.254	0.224	0.181	0.086	0.101	0.127	-
SoilSCAPE	0.422	0.483	0.598	0.445	0.458	0.227	0.201

- All 4 networks show inverse correlation of $\theta - \Delta T$, regression fit lines to different NDVI classes have similar slopes.
- The higher NDVI classes correspond to greater temperature changes.
- The complex land cover types (cropland or grassland/forest mixing) can contribute to the relatively lower R^2.
- R^2 does not show a clear increasing/decreasing trend as the NDVI increases for three networks only except SoilSCAPE.

$\theta - \Delta T_s$ MODEL EVALUATION

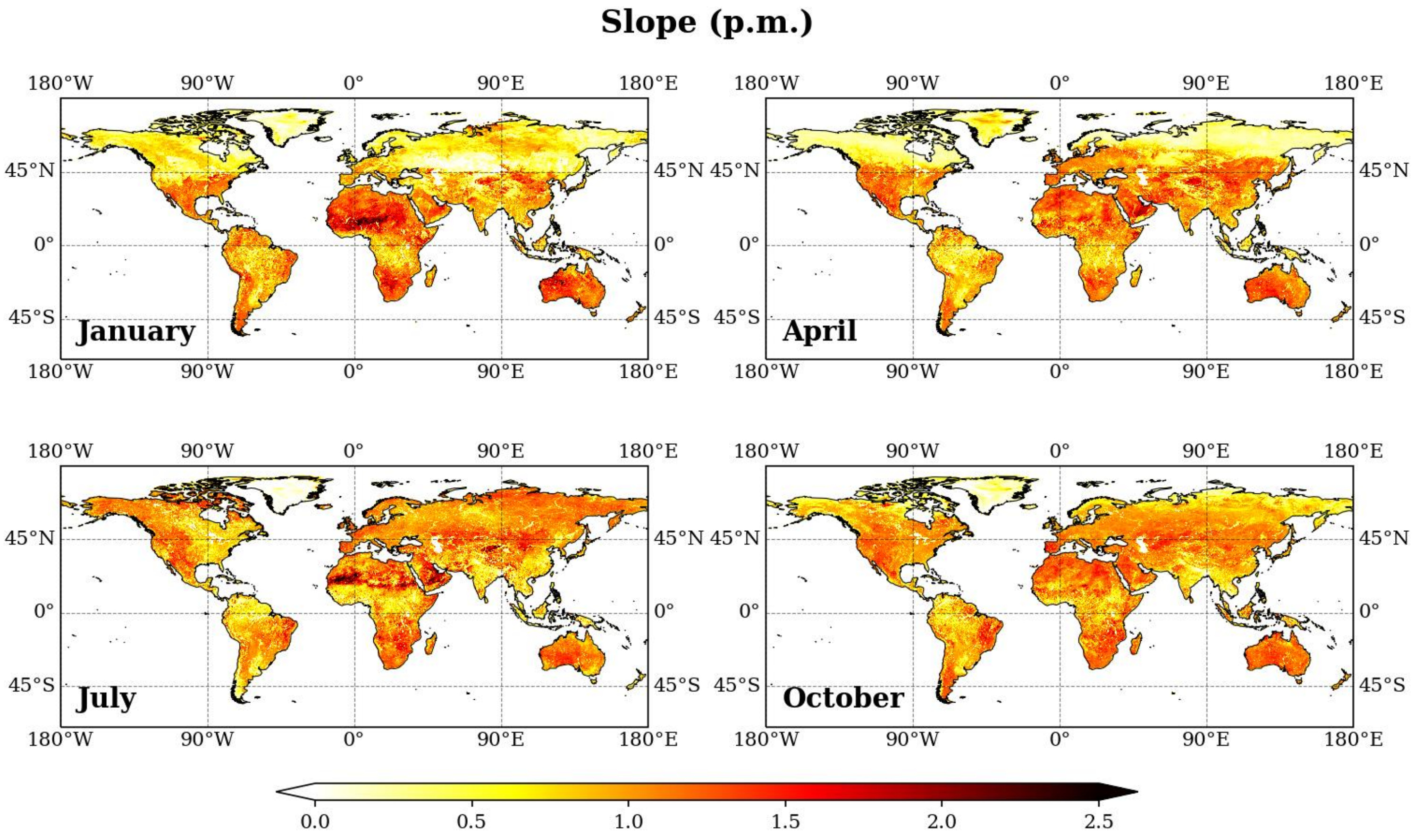




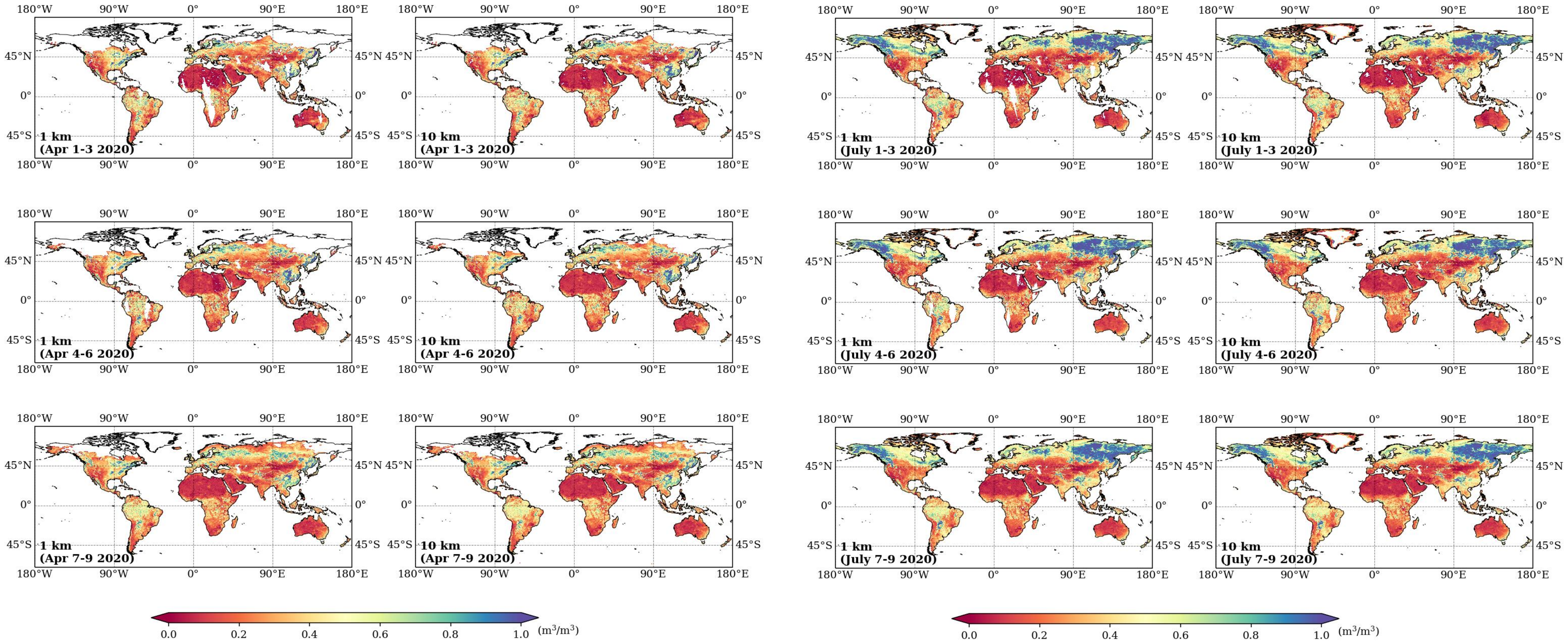
- High/middle latitudes of the Northern Hemisphere have greater seasonal variations of R^2.
- The Southern Hemisphere does not show the seasonal variations as great as Northern Hemisphere.
- RMSE maps show similar spatial and seasonal patterns as the R^2 maps. The highest RMSEs can be found in the regions of Central Asia, North Africa near or above the 45^{o}N latitude line,
- The high-altitude regions of Rocky, Andes, Alps and Himalayan mountains consistently have high RMSE.

The statistical metrics of the AMSR2 Tb – MODIS LST model of ascending overpass (1:30 p.m.) from 2015-2020

$\theta - \Delta T_s$ MODEL EVALUATION

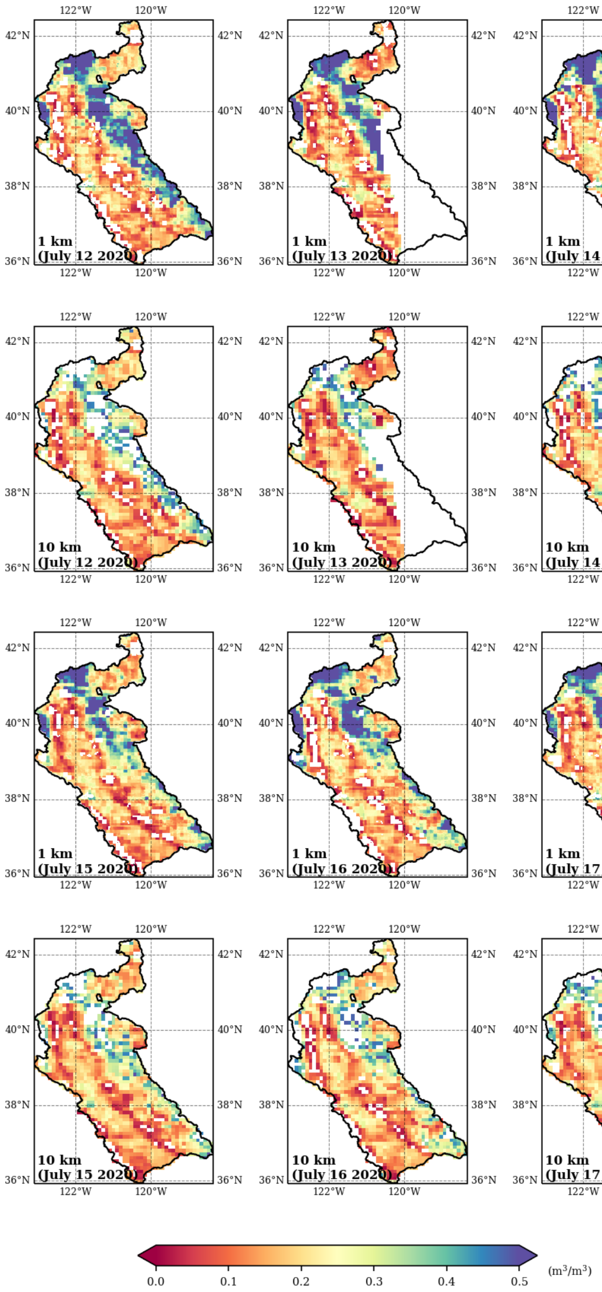


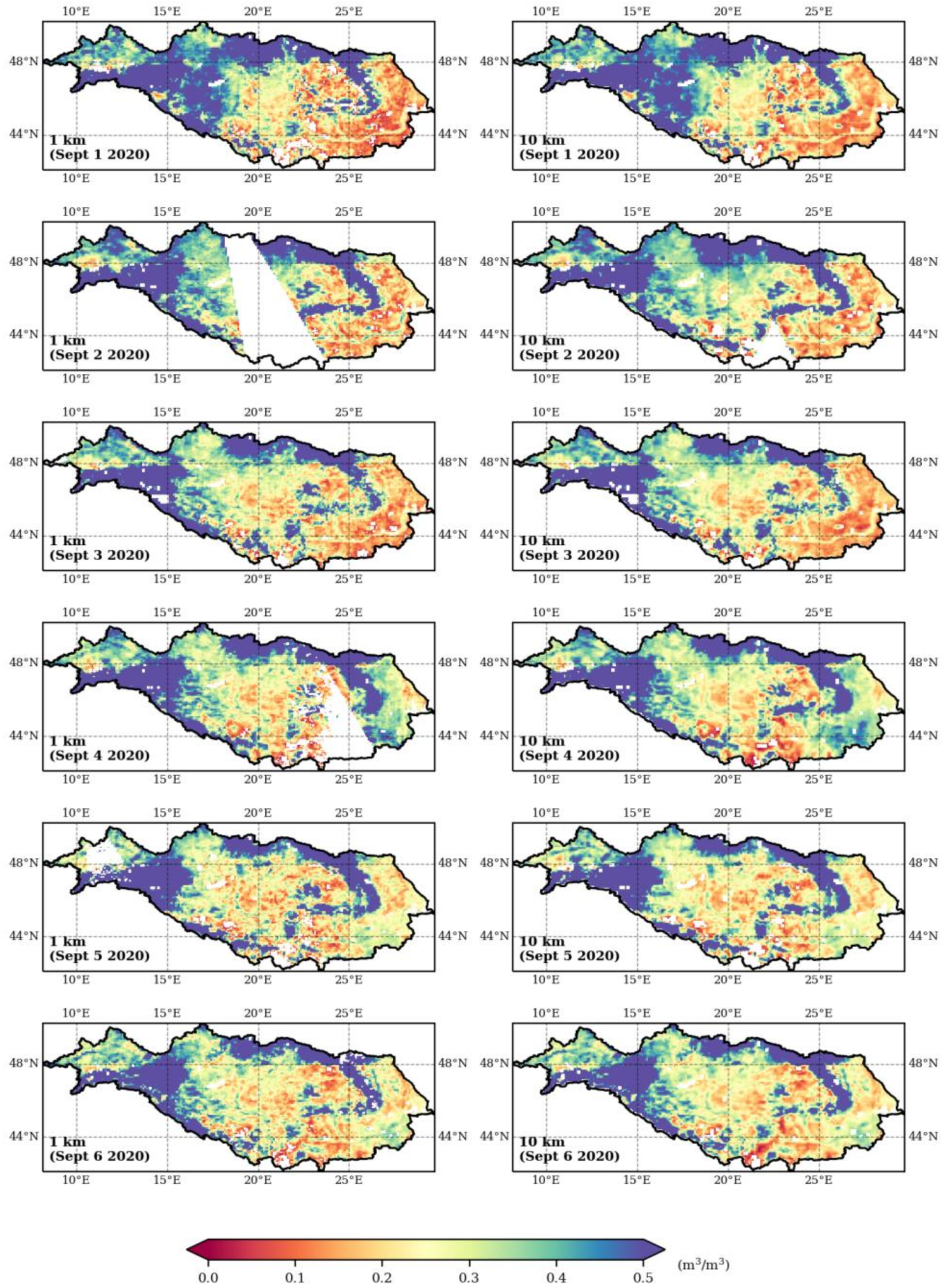
- High latitude regions above 45°N line have large seasonal variation of slope and low values in cold months.



The global 3-day composite downscaled 1 km using gap-filled MODIS LST, and 10 km AMSR2 SM from January and July, 2020.

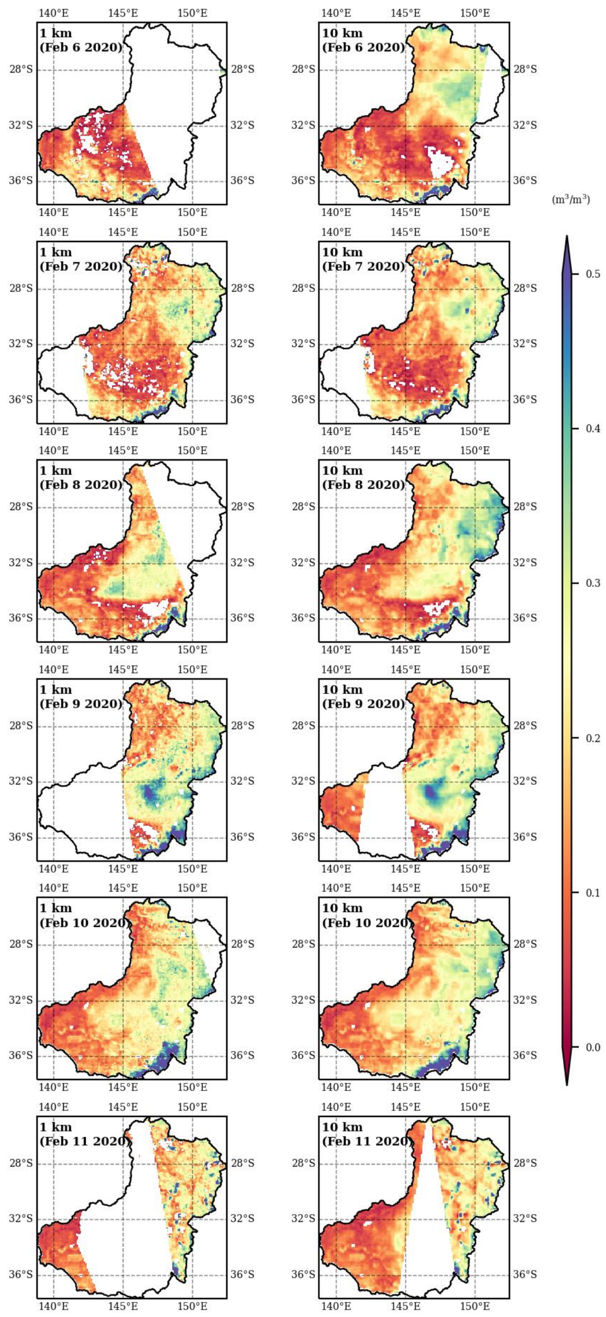
- The global 1 km SM data was produced with the dimensions of 14616 rows × 34704 columns and in EASE grid projection.
- The 1 km SM have similar spatial patterns as 10 km SM, but demonstrate greater spatial variability at the smaller scale.
- 1 km SM had less missing data in high latitude regions in July than April.
- 1 km/10 km SM data were overestimated in high latitude regions in July.





The daily composite downscaled 1 km using gap-filled MODIS LST, and 10 km AMSR2 SM in 2020 from Sacramento-San Joaquin RB and Danube RB.

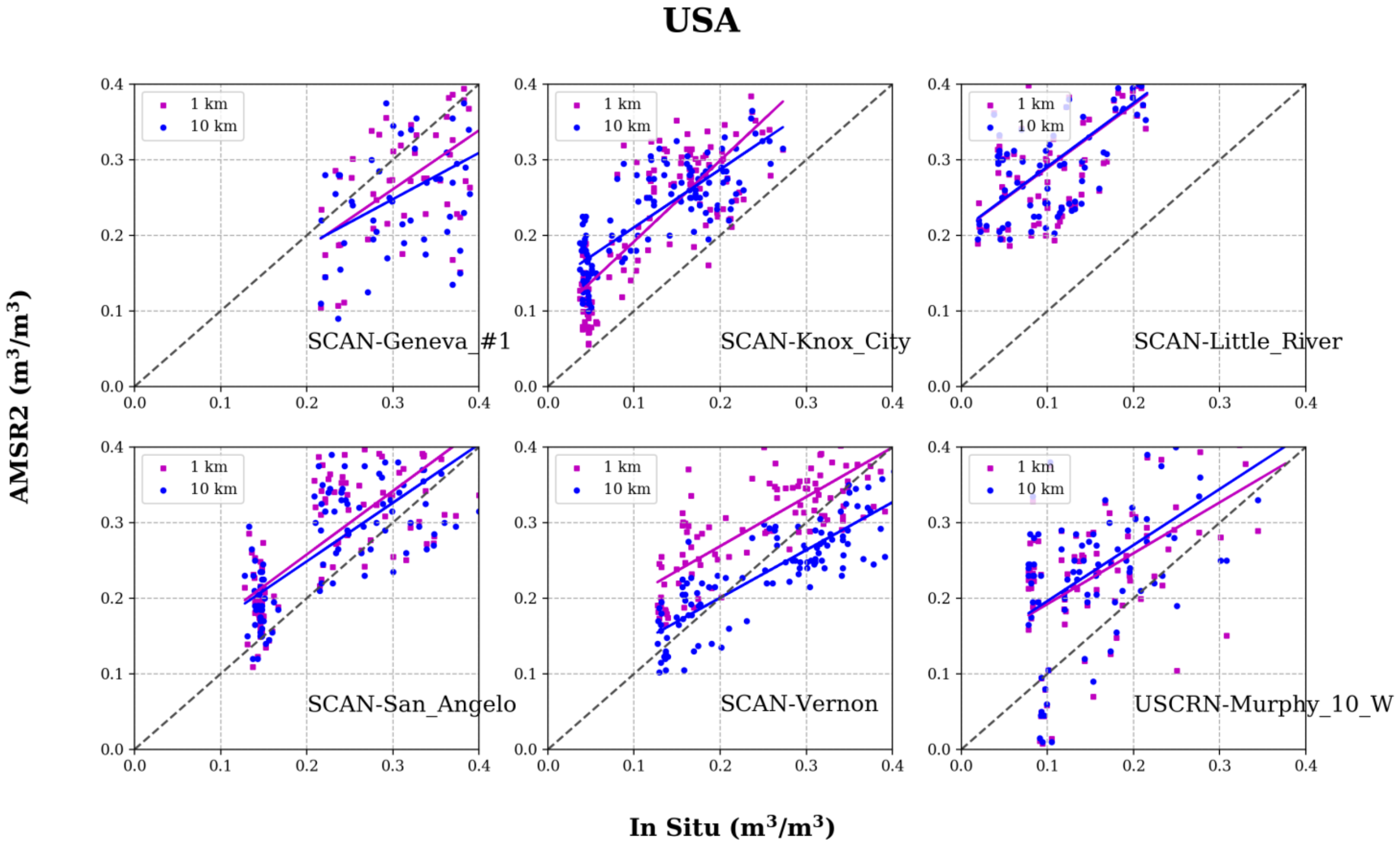
- The western and southern portions of SSJRB were consistently dry and presented many hot spots in July, which can be related to the potential wildfire threat regions.
- The central and eastern parts of the DRB showed greater spatial variability in 1 km SM.



- In MDRB, the 1 km SM in April had the greatest spatial variability, corresponding to the wettest month. The entire MDRB showed an SM wetting trend, indicated the drought conditions were relieved.

The daily composite downscaled 1 km using gap-filled MODIS LST, and 10 km AMSR2 SM in 2020 from Murray-Darling RB.

SM Validation (USA) in 2019-2020



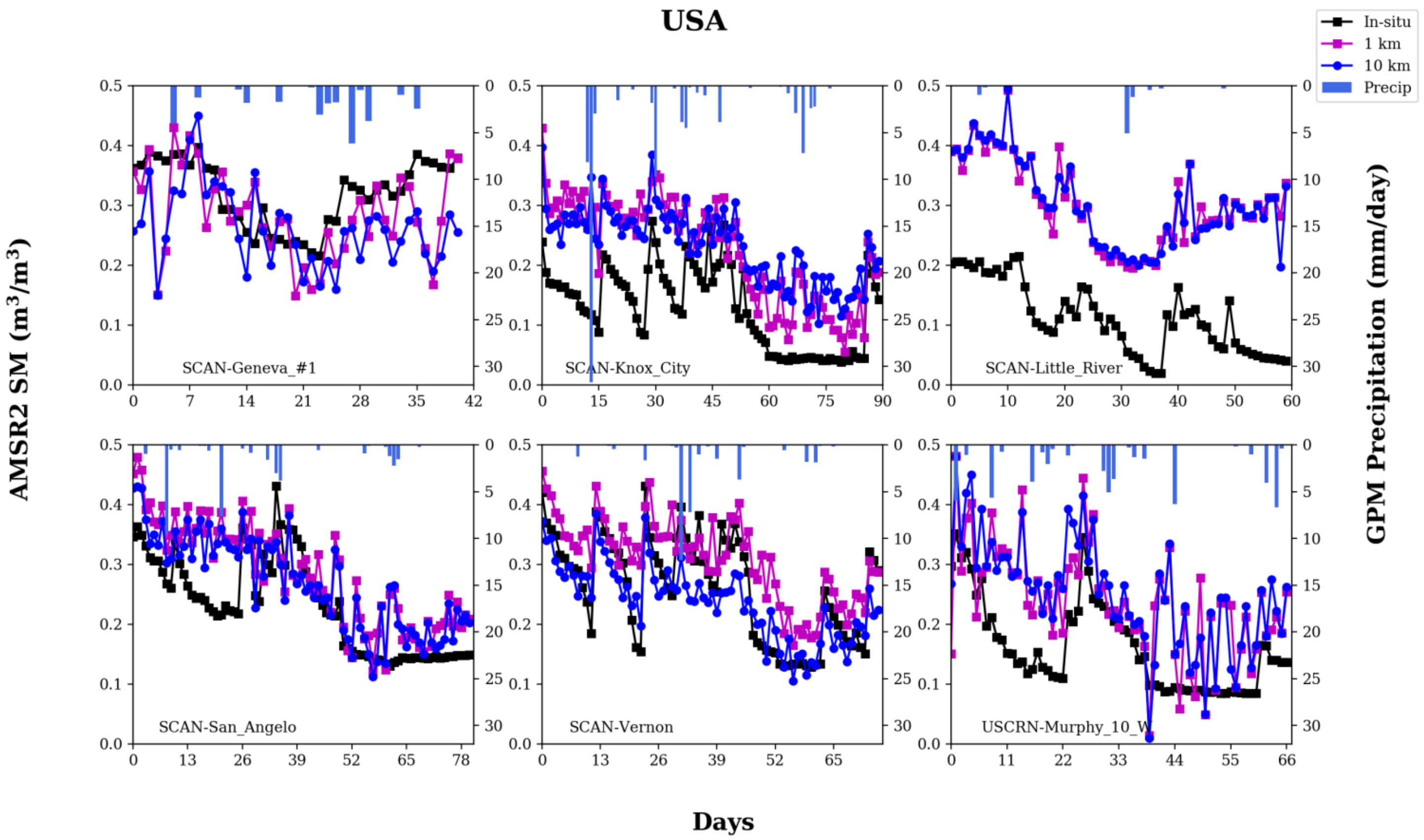
R^2 values are higher for 1 km SM than 10 km SM over most of stations.

Overall the 1 km SM validation R^2 are higher than the 10 km SM, while ubRMSE and bias are averagely decreased for all stations.

Fit lines of 1 km SM data pairs are closer to the diagonal line than 10 km data.

Site Name	SM Network	Number	1 km AMSR2			10 km AMSR2		
			R^2	ubRMSE	bias	R^2	ubRMSE	bias
Geneva, NY	SCAN	53	0.31	0.043	0.04	0.183	0.062	0.058
Knox City, TX	SCAN	121	0.65	0.096	-0.094	0.63	0.105	-0.104
Little River, GA	SCAN	84	0.466	0.188	-0.187	0.454	0.189	-0.189
San Angelo, TX	USCRN	107	0.58	0.05	-0.053	0.575	0.046	-0.042
Vernon, TX	USCRN	111	0.725	0.039	-0.042	0.664	0.058	-0.049
Murphy, ID	USCRN	88	0.295	0.075	-0.073	0.246	0.083	-0.081

Time series of AMSR2 SM and GPM precipitation (USA) of 2020



- On the days with less or no rain, there was less discrepancy between 1 km / 10 km AMSR2 SM and in situ SM.
- 1 km SM generally better agreed to in situ SM than 10 km SM.

Summary

- The gap-filling model evaluation results show that the model performs better in middle/low latitude regions than high latitude. Besides, the high-altitude mountainous regions tend to have higher RMSEs and limited model performance.
- Validation metrics show that overall ubRMSE and bias for 1 km AMSR2 SM are clearly decreased from 10 km, while the overall R^2 shows a slight degradation.
- The SM stations located at semi-arid climate zone and sparse vegetation cover outperform the stations at humid climate zone and high vegetation cover.