Development and Evaluation of a New Temperature Effect Removal Algorithm for AMSR2 Satellite Soil Moisture Product using Brightness Temperature

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Content

- The current methods to estimate the soil moisture
- Existence of Temperature Effect (TE) in *in-situ* and satellite Soil Water Content (SWC) data
- Objectives
- Study Area and data description
- Methodology
- Application
- Results

The current methods to estimate the soil water content

Soil Moisture Methods

- Soil moisture estimating models
- Ground based techniques
  - The gravimetric method (oven drying)
  - Neutron probe technology
  - **Dielectrically measured methods**
    - Time Domain Reflectometry sensors (TDR)
    - Capacitance and Frequency Domain Reflectometry sensors (FDR)
- Satellite remote sensing observation

Examples for satellite that used to obtain soil moisture: SMMR, AMSR-E, SMOS, SMAP, **AMSR2**

Importance of satellite observation soil moisture

- Agricultural monitoring
- Drought and flood forecasting
- Forest fire prediction
- Water supply management

Existence of Temperature Effect (TE) in *in-situ* and satellite Soil Water Content (SWC) data

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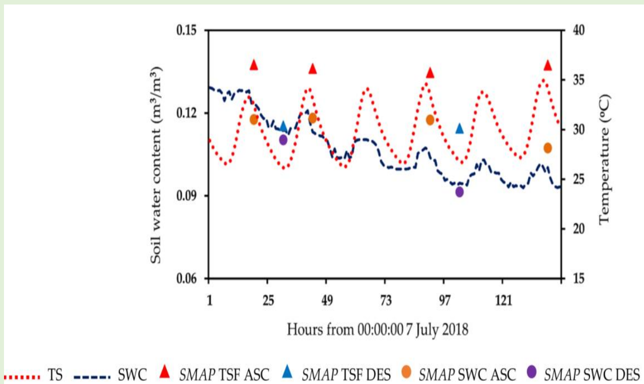
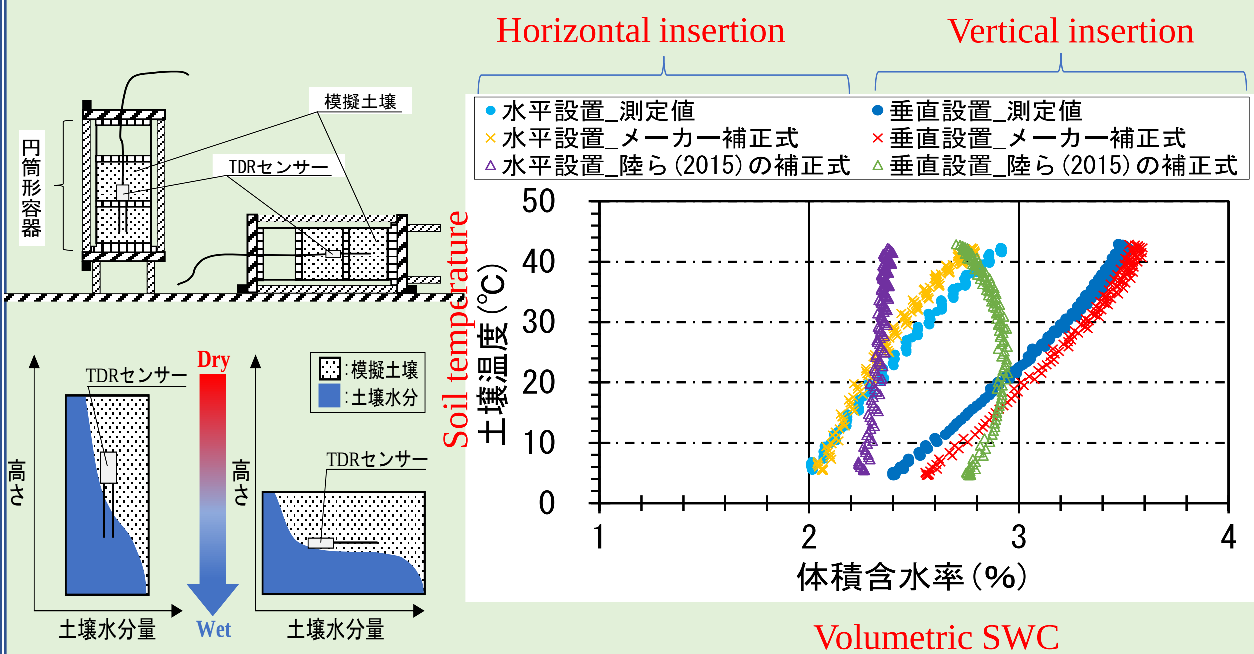
Satellite soil water content products



Areal mean of *in-situ* SWC, soil temperature, SMAP SWC at ascending and descending times and SMAP surface temperature at Oklahoma, USA (Hoang and Lu (2021))



(Yamamato and Lu, 2022)

Problem Statement

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- Satellite data used the same physical base as *in-situ* data, the bulk dielectric constant;
- Satellite data used *in-situ* soil moisture as the ground truth for calibration and validation process

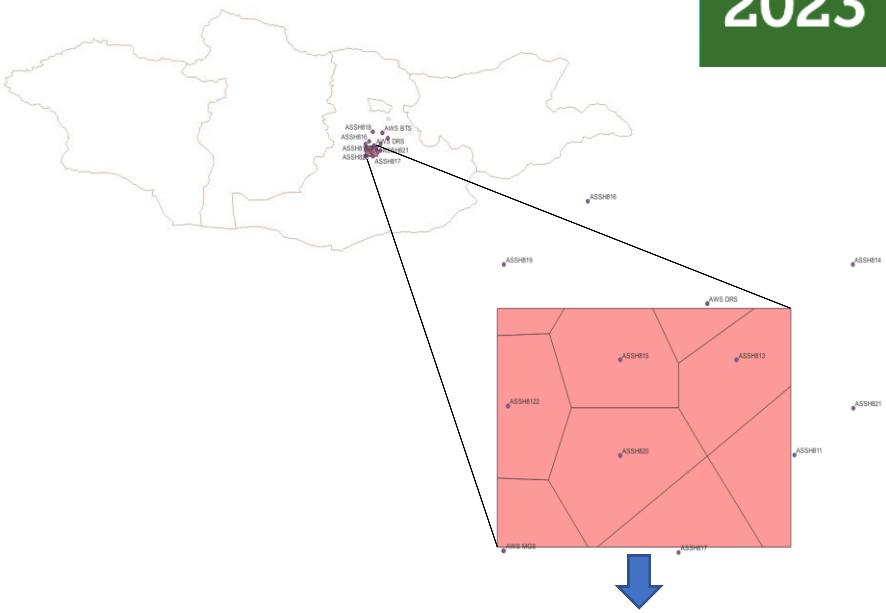
➢ The impact and removal of temperature effects on satellite soil water content (AMSR2) still need to be evaluate

Objectives

- Confirmation of the temperature effect on AMSR2 SWC data
- Develop the new temperature effect removal method which is suitable for satellite SWC data
- Evaluate the impact of that correction in AMSR2 satellite soil water content data

Study area and data description

Study area: Mongolia



- ***In-situ* data**

  - **3cm depth** soil water content and soil temperature were selected
  - Accessed from the website of GCOM-W1 Research Product Distribution Service (https://suzaku.eorc.jaxa.jp/GCOM_W/research/resdist.html)
  - Only 9 stations have been selected from **5th Sep, 2016 to 31st Oct, 2019**
  - The *in-situ* data has been weighted by using Thiessen polygon method correspond to the resolution of satellite data

- **Satellite data**

  - AMSR2 **level 2** soil moisture product at **50km X 50km / 0.5 x 0.5 degree** spatial resolution
  - Obtained from the G-Portal System website (https://gportal.jaxa.jp/gpr/search?tab=0)
  - Local crossing times AMSR2 are around 1:30p.m. and 1:30a.m. respectively for ascending and descending over passes.

Station name	Station ID	Network	Weighing
ASSH820	C2	ASSH	0.204038
ASSH815	C4	ASSH	0.158021
ASSH8122	A3E	ASSH	0.129942
ASSH817	D1	ASSH	0.107943
ASSH813	E4	ASSH	0.155352
ASSH819	A6	ASSH	0.022081
ASSH811	F2	ASSH	0.114076
MGS		AWS	0.06894
DRS		AWS	0.039608

Methodology

- Analyzing the trend of Ascending (ASC) and Descending (DES) crossing time soil water content from both satellite and *in-situ* observation
- Analyzing and developing the temperature effect error removal method for satellite soil water content products
- Applying the temperature effect removal method to confirm and evaluate the impacts of these effects on satellite SWC data

Temperature effect removal in *in-situ* data

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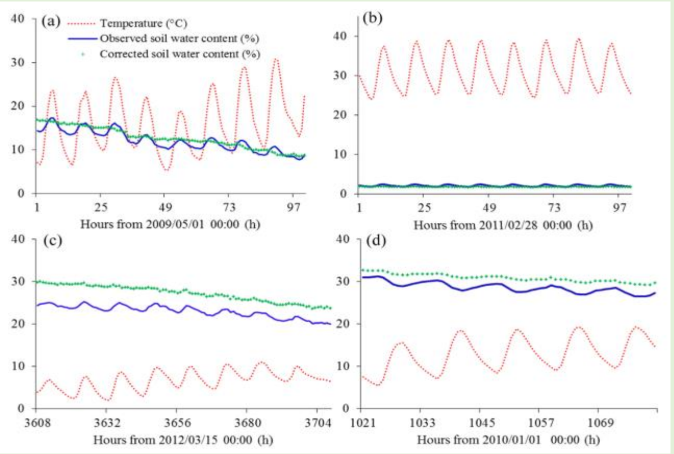
The data- driven method (Lu et al., 2015)

$$A_\theta = \alpha\theta_d A_T$$

- A_θ = *Daily amplitude of Soil Water Content (SWC)*
- α = *Temperature correction coefficient*
- θ_d = *Daily Soil Water Content*
- A_T = *Daily amplitude of Soil Temperature (ST)*



Application of the automated temperature effects removal (Kapilaratne and Lu, 2017, 10.1016/j.jhydrol.2017.05.050) to *in-situ* data.

The correction equation

$$\theta_{ref} = \theta(1 - \alpha\left(T - T_{ref}\right))$$

T_{ref} = *Reference temperature at which calibration cure to calculate SWC from sensor reading was made.*

θ_{ref} = *SWC when the soil temperature equals to Reference temperature.* It is considered the calibration curve will give correct value.

For satellite data, only ASC and DES data are available.
It is difficult to estimate amplitudes.

Following changes should be considered.

A_θ → Change of SWC
A_T → Change of T
θ_d → Mean SWC

Temperature effect removal in satellite data

Triangle method for satellite data

$$\Delta\boldsymbol{\theta} = \boldsymbol{\alpha}\boldsymbol{\theta}_{\boldsymbol{ref}}\Delta\boldsymbol{T}$$

- $\Delta\boldsymbol{\theta}$ $= Change\ of\ Soil\ Water\ Content\ (SWC)$
- $\boldsymbol{\alpha}$ $= Temperature\ correction\ coefficient$
- $\boldsymbol{\theta}_{\boldsymbol{ref}}$ $= Average\ Soil\ Water\ Content$
- $\Delta\boldsymbol{T}$ $= Change\ of\ Temperature\ (T)$

The correction equation for satellite data

$$\boldsymbol{\theta}_{\boldsymbol{ref}} = \boldsymbol{\theta}\left(\mathbf{1} - \boldsymbol{\alpha}\left(\boldsymbol{T} - \boldsymbol{T}_{\boldsymbol{ref}}\right)\right)$$

$\boldsymbol{T}_{\boldsymbol{ref}} = Reference\ temperature\ at\ which\ calibration$

$cure\ to\ \ calculate\ SWC\ from\ sensor\ reading\ was\ made.$

Temperature data:

- Using soil temperature as a surrogate at development stage
- Using satellite surface temperature product or brightness temperature

Calculation of difference:

$$\Delta\boldsymbol{\theta} = \left(\theta_{asc,p} - \theta_{des}\right)\ or\ \left(\theta_{asc,f} - \theta_{des}\right)$$

$$\Delta\boldsymbol{T} = \left(T_{asc,p} - T_{des}\right)\ or\ \left(T_{asc,f} - T_{des}\right)$$

$$\boldsymbol{\theta}_{\boldsymbol{ref}} = use\ average\ as\ approximation$$

asc : ascending   des : descending
p : previous   f : following

Temperature effect removal in satellite data cont.

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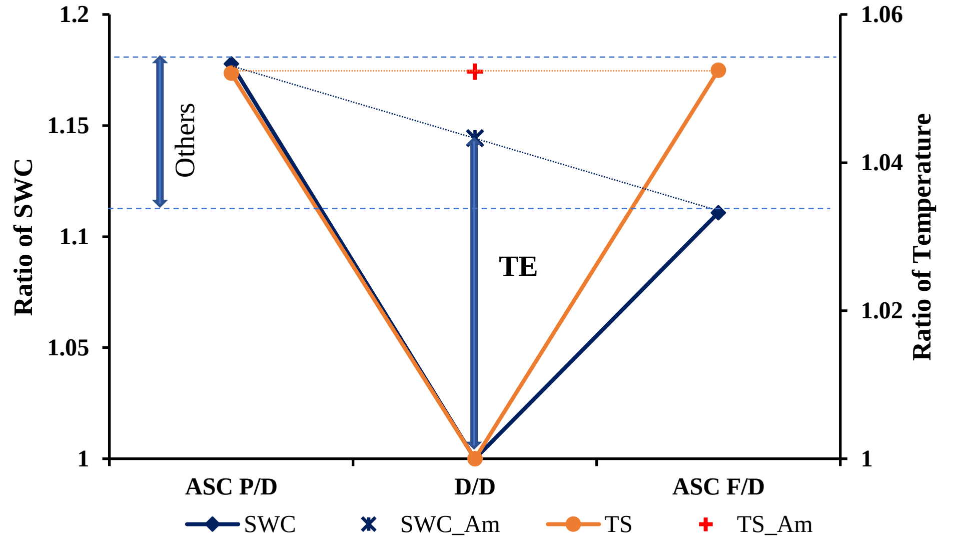
Temperature data:

- Using soil temperature as a surrogate at development stage
- Using soil temperature, surface temperature and **satellite brightness temperature product**



The summarization of the trend of normalized ASC and DES soil water content and soil temperature data of AMSR2

ASC P : Ascending Previous
D : Descending
ASC F : Ascending Following

Calculation of difference:

$$\boldsymbol{\Delta\theta} = (\theta_{asc,p} - \theta_{des})\ or\ (\theta_{asc,f} - \theta_{des})$$

$$\boldsymbol{\Delta T} = (T_{asc,p} - T_{des})\ or\ (T_{asc,f} - T_{des})$$

$$\boldsymbol{\theta_{ref}} = use\ average\ as\ approximation$$

asc: ascending des : descending
p : previous f : following

$$\theta_{asc,m} - \theta_{des} = (\theta_{asc,p} + \theta_{asc,f})/2 - \theta_{des}$$

$$T_{asc,m} - T_{des} = (T_{asc,p} + T_{asc,f})/2 - T_{des}$$

$$\bar{\theta} = (\theta_{asc,m} + \theta_{des})/2$$

$$\longrightarrow \theta_{asc,m} - \theta_{des} = \boldsymbol{\alpha\bar{\theta}}\,(T_{asc,m} - T_{des}) \longrightarrow \boldsymbol{\Delta\theta} = \boldsymbol{\alpha\theta_{ref}\Delta T}$$

Where m means average of previous and following ascending

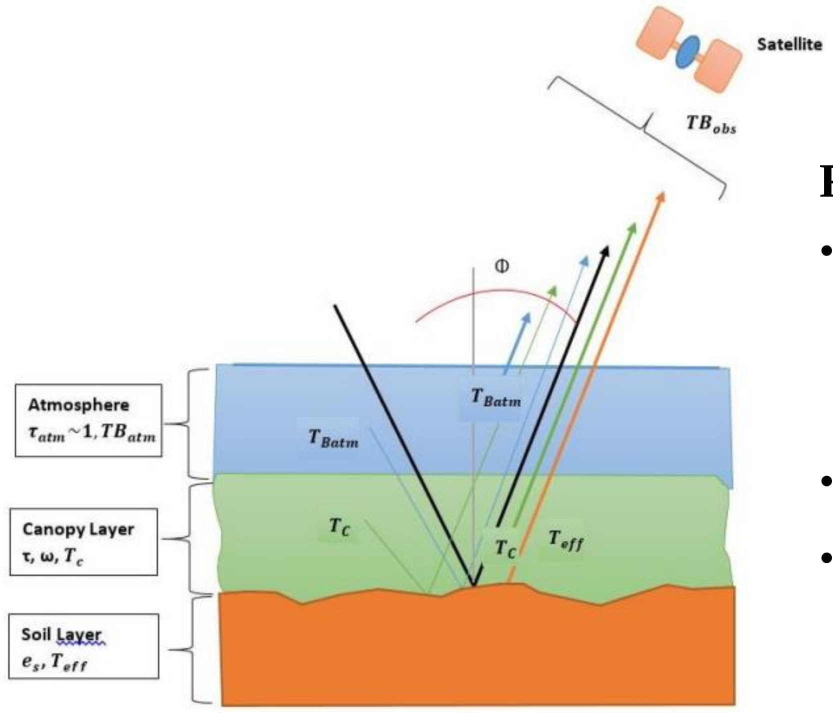
Brightness Temperature (TB)

Satellite observation

Basing on the dependency of the microwave measurement on the dielectric properties

$$TB_{c,p} = TB_{s,p}.e^{-\tau_c} + (1-\omega_c)(1-e^{-\tau_c})T_c + (1-\omega_c)(1-e^{-\tau_c}).T_c.\Gamma(\theta,p).e^{-\tau_c} \quad (1)$$

$$TB_{s,p} = \left[1 - \{(1-Q).\Gamma(\theta,p) + Q.\Gamma(\theta,q)\}.e^{-h' cos^2\theta}\right].T_s \qquad (2)$$



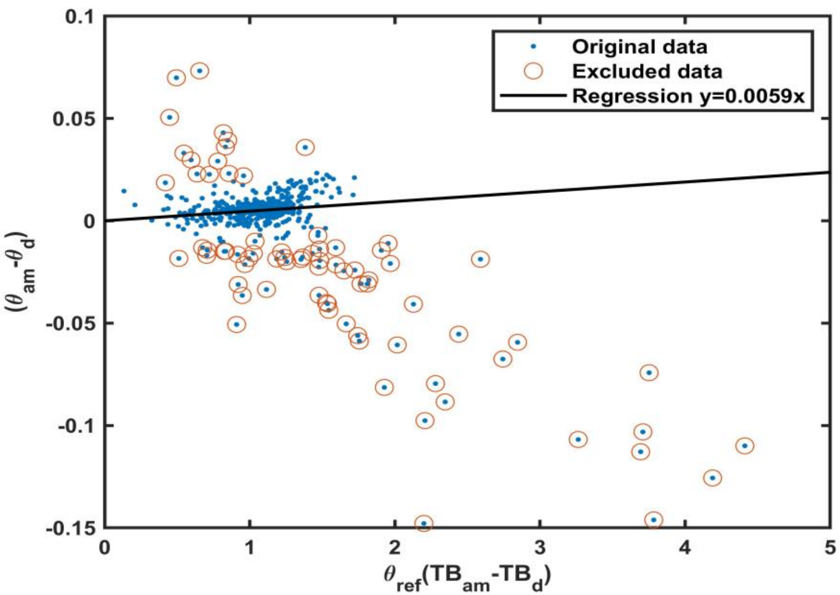
Reasons for using Brightness Temperature (TB)

- Brightness temperature is a basic observable quantity calculated from the antenna temperature of a microwave radiometer.
- Can be directly measure from the satellite
- Surface temperature can be obtained through the brightness temperature

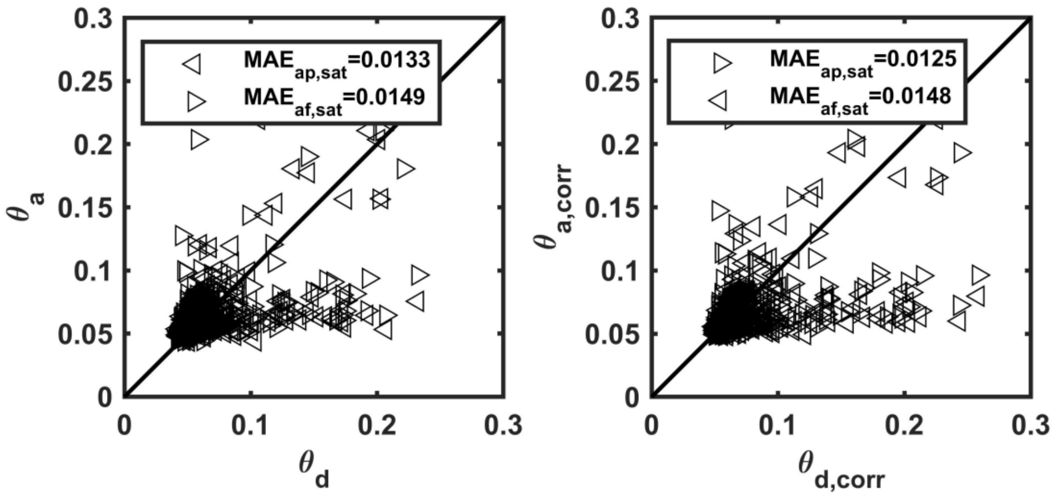
Application: Temperature effect removal

Applying newly developed method to satellite SWC products using brightness temperature (TB)

$$\theta_{asc.m} - \theta_{des} = \boldsymbol{\alpha\bar{\theta}}\ (TB_{asc,m} - TB_{des})$$

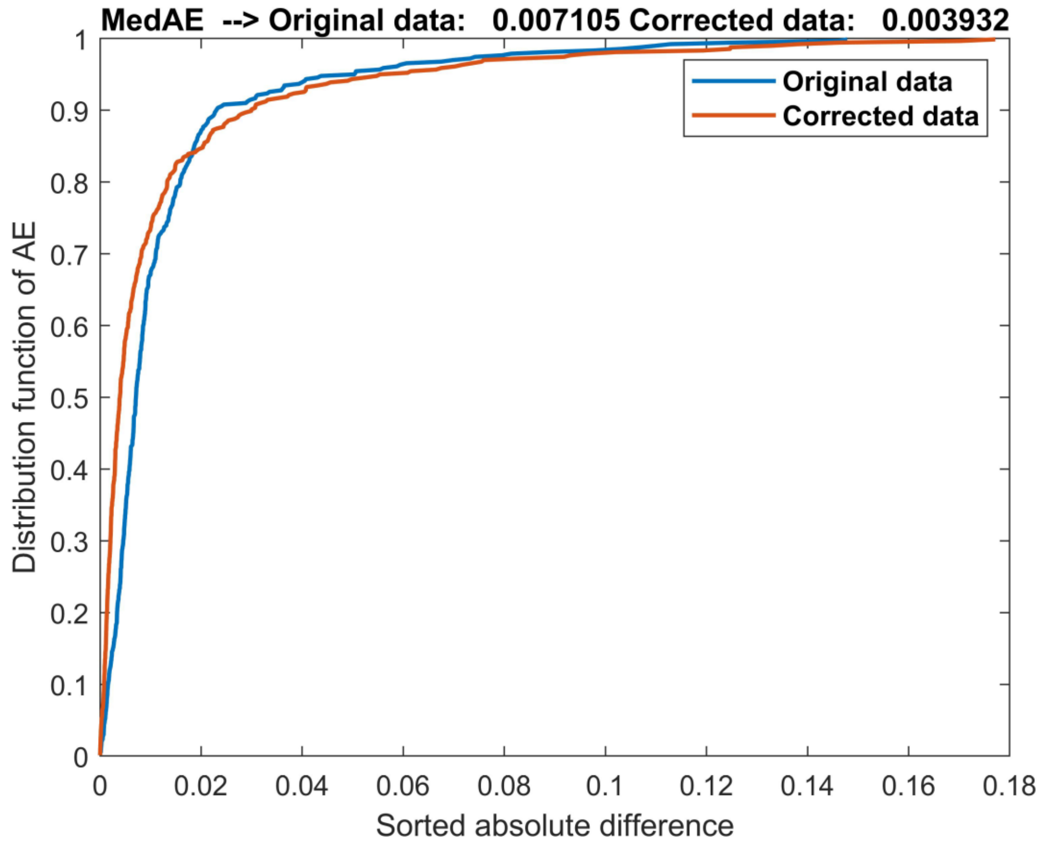


Finding the temperature effect coefficient (α)



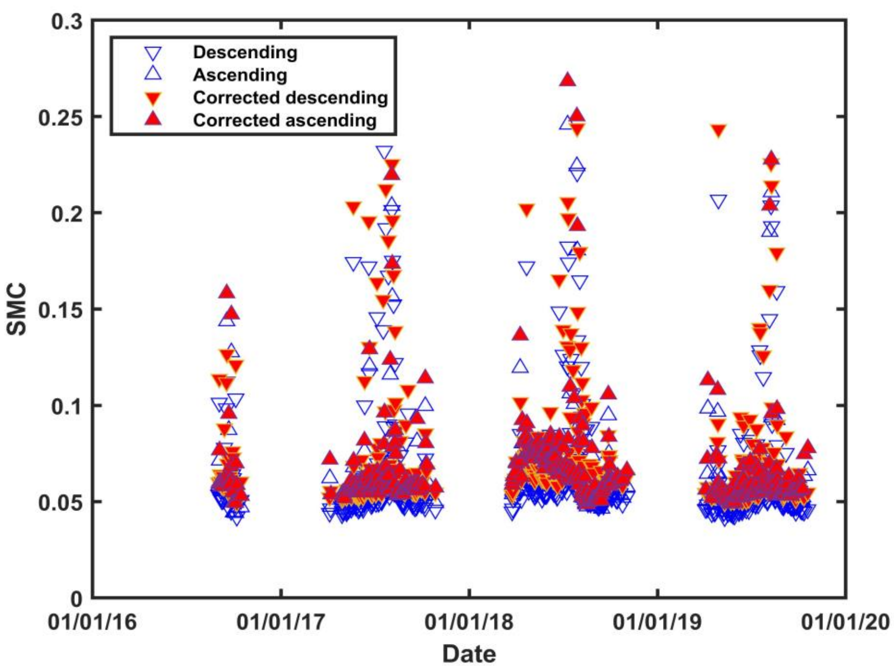
Results and effects of temperature effect error removal for satellite data

Application: Temperature effect removal Cont.

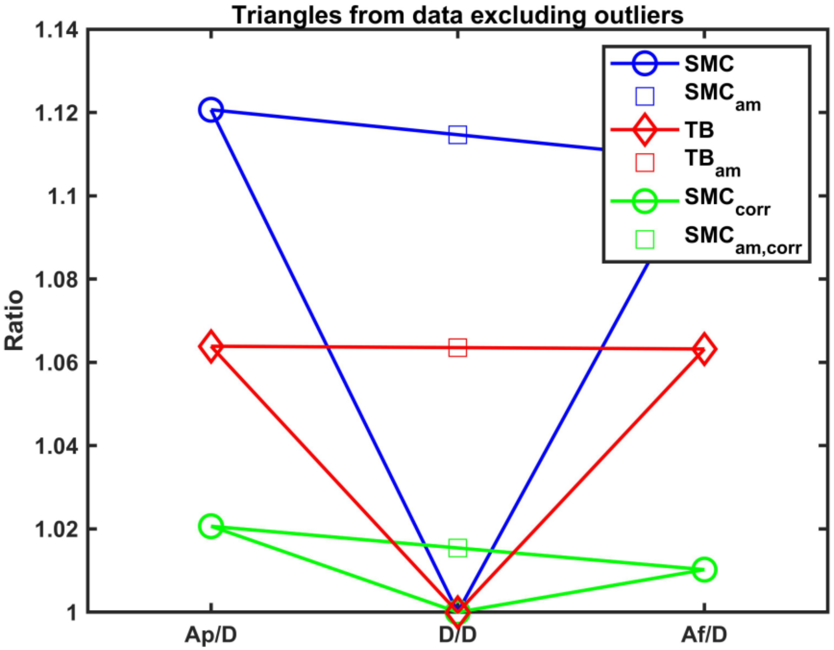


Accumulation of absolute error in satellite soil moisture data

Results of temperature effect removal



A diagram of original and corrected AMSR2 ASC and DES SWC data



A diagram of after removing the TE on AMSR2 satellite SWC data by using brightness temperature data (TB)

Conclusion

- Found the temperature effect also exist in the AMSR2 SWC data
- Temperature effect on AMSR2 SWC data at Mongolia site was successfully removed using the brightness temperature (TB) data

THANK YOU

Data: Satellite data: Study area and data description

- The study area is set to an area of 50 x 50 km that corresponding to the AMSR2 pixel of AMSR2 SWC (AMSR 2 Level 2 (L2) Soil Moisture Content (SMC) data products)..
- Depending on the data quality and availability, the pixel that covers M1 area was selected for evaluation of the removal temperature effect method.
- The in situ data are all averaged over the M1 area for comparison and evaluation.
- The data period was chosen based on the longest data series. Since the data at C2 and A6 are not available from 1st Oct, 2015 to 4th Sep, 2016, the selected period for study ranges from 5th Sep, 2016 to 31st Oct, 2019.
- Surface temperature product is also used.

Data Assessment

- When we analyzing the data first we have to eliminate the abnormal data (data that have drops or spikes)
- To avoid the effects of precipitation because of the rainfall the days that have a daily rainfall amount larger than 0.1mm have been excluded
- And also the days with negative soil temperature are excluded because the TDR calibration equation is not applicable to frozen soil

Data: In situ data averaging - Thiessen Polygon Method

$$P_{Avg} = \left(\sum_{i=1}^{n} A_i \times P_i\right) / \ A$$

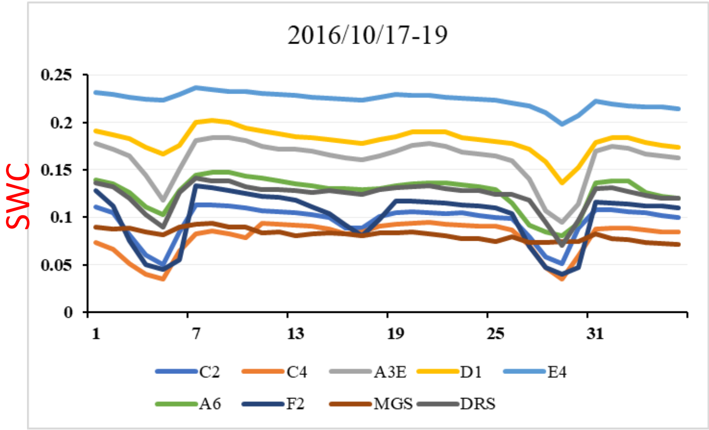
$$SWC_{Avg} = \left(\sum_{i=1}^{n} A_i \times SWC_i\right) / \ A$$

$$ST_{Avg} = \left(\sum_{i=1}^{n} A_i \times ST_i\right) / \ A$$

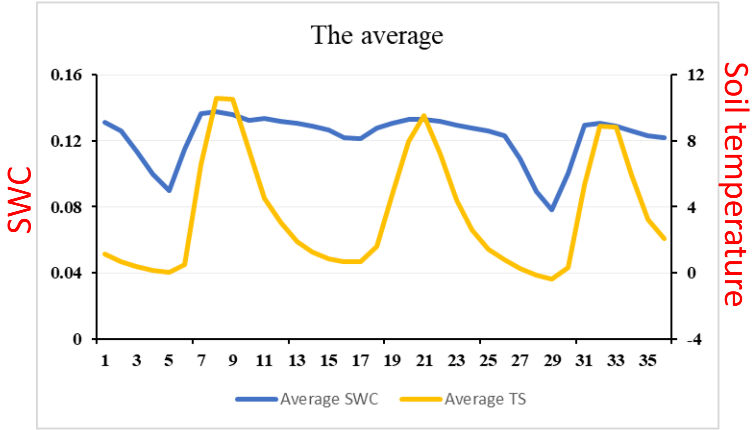
P_i, ST_i, SWC_i = **Precipitation, Soil Temperature, Soil Water Content** (SWC) **recorded at various stations.**

A_i = **Area of Thiessen polygon** i

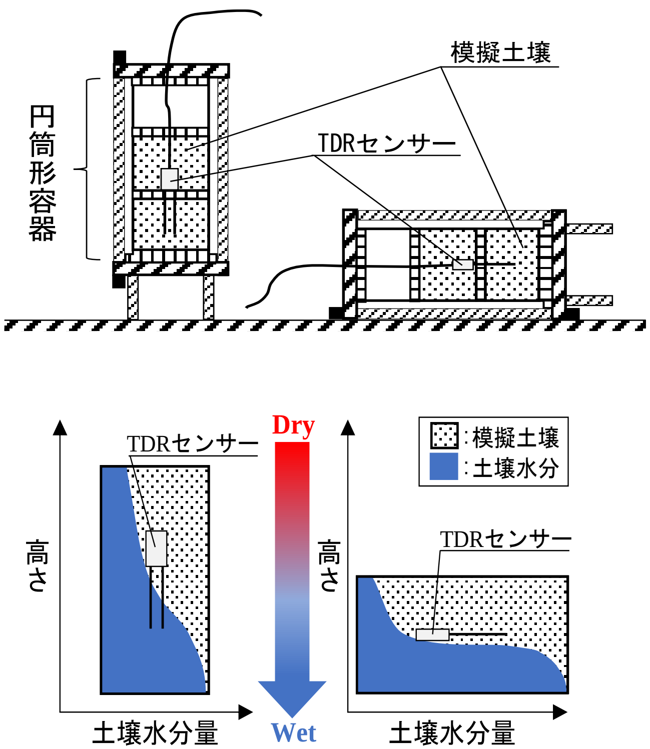
n = **Number of stations**

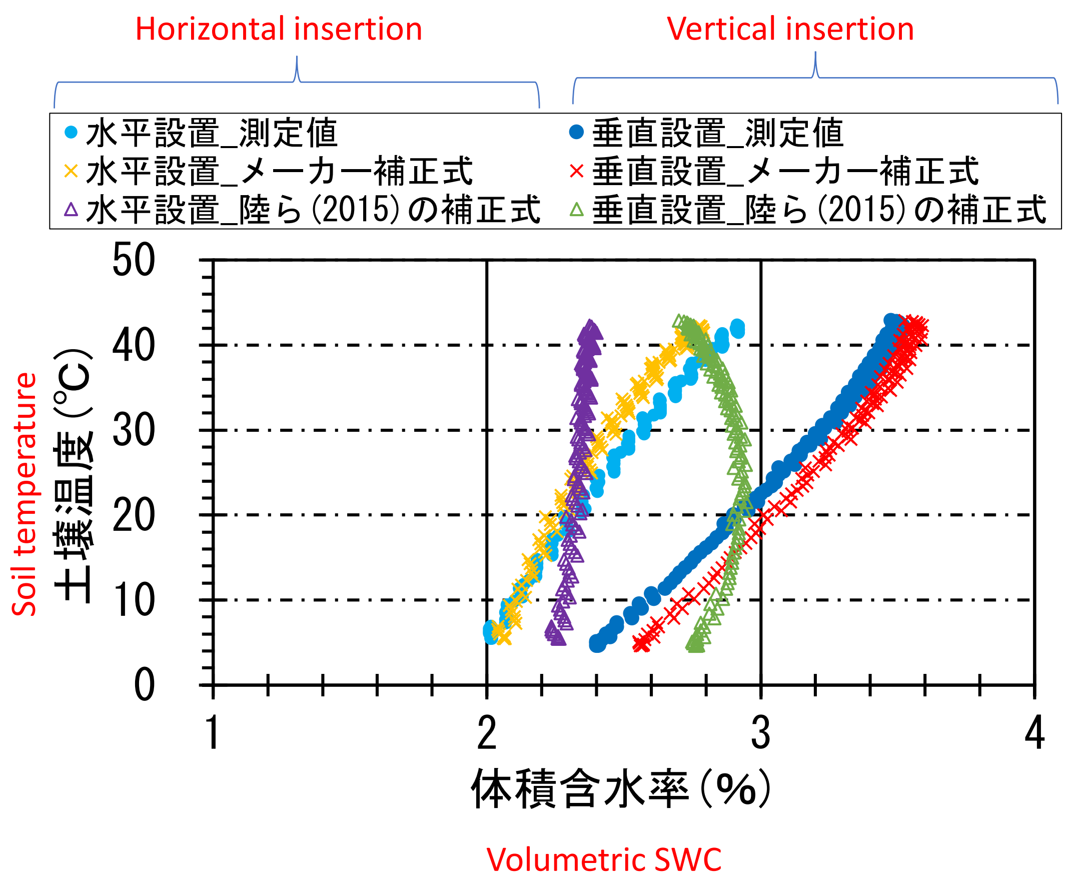


Spatially averaged data will be used.



Experimental facts about TE in TDR SWC measurement





Study area and data description

- Weighing index

Station name	Station ID	Network	Weighing
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ASSH811	F2	ASSH	0.114076
MGS		AWS	0.06894
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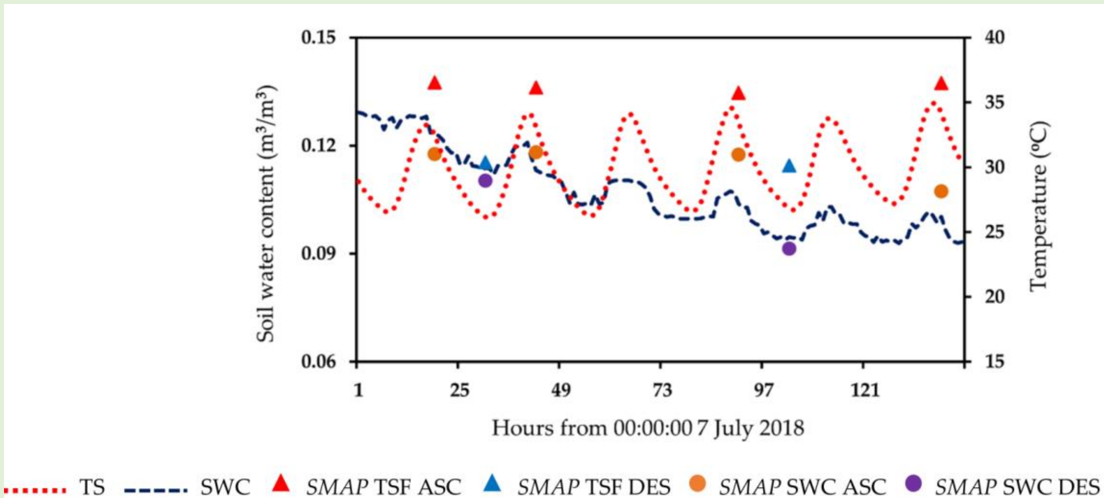
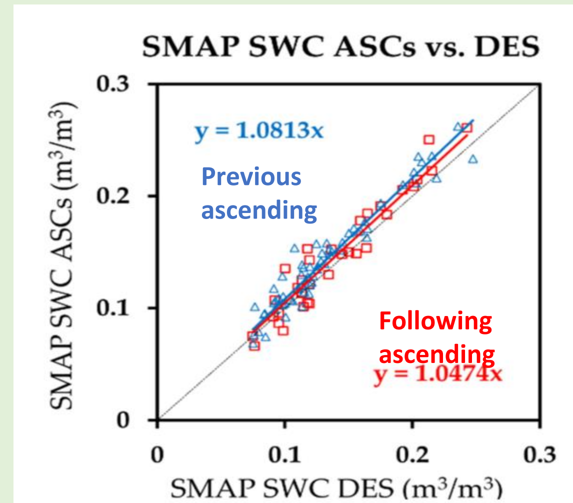
Existence of Temperature Effect (TE) in satellite Soil Water Content (SWC) data



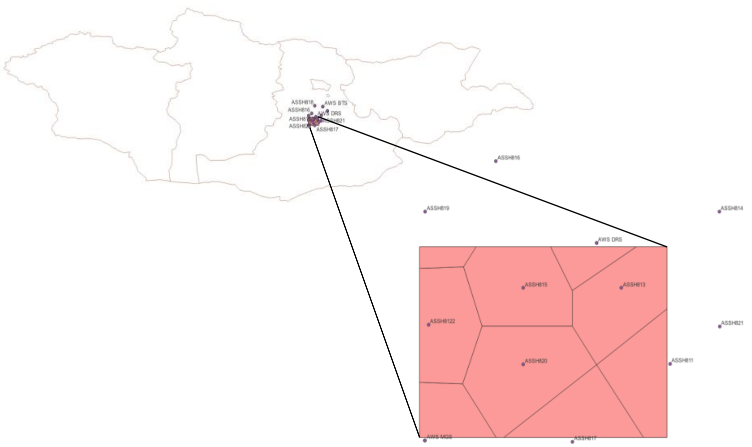


Areal mean of *in-situ* SWC, soil temperature, SMAP SWC at ascending and descending times and SMAP surface temperature at Oklahoma, USA (Hoang and Lu (2021))

Both ascending SWC are larger than descending SWC. Previous ascending SWC are larger than following ascending SWC (Hoang and Lu (2021)) .

Study Area

- Study area : Mongolia



- Depending on the data quality and availability, the pixel that covers M1 area was selected for evaluation of the removal temperature effect method.
- Annual rainfall 300mm-400mm
- Land cover : forest, meadow steppe, real steppe, desert steppe, barren, sand, desert, ice, water, cropland and built area
- Time in Mongolia is officially represented by the Mongolian Standard Time (UTC+08:00) However, the far western provinces of Khovd, Uvs and Bayan-Ölgii use UTC+07:00.
- This study area is located between 45.75°N, 106.9°E and 46.2°N, 106.25°E

Outliers

- outlier is an extremely high or extremely low data point relative to the nearest data point and the rest of the neighboring co-existing values in a data graph or dataset

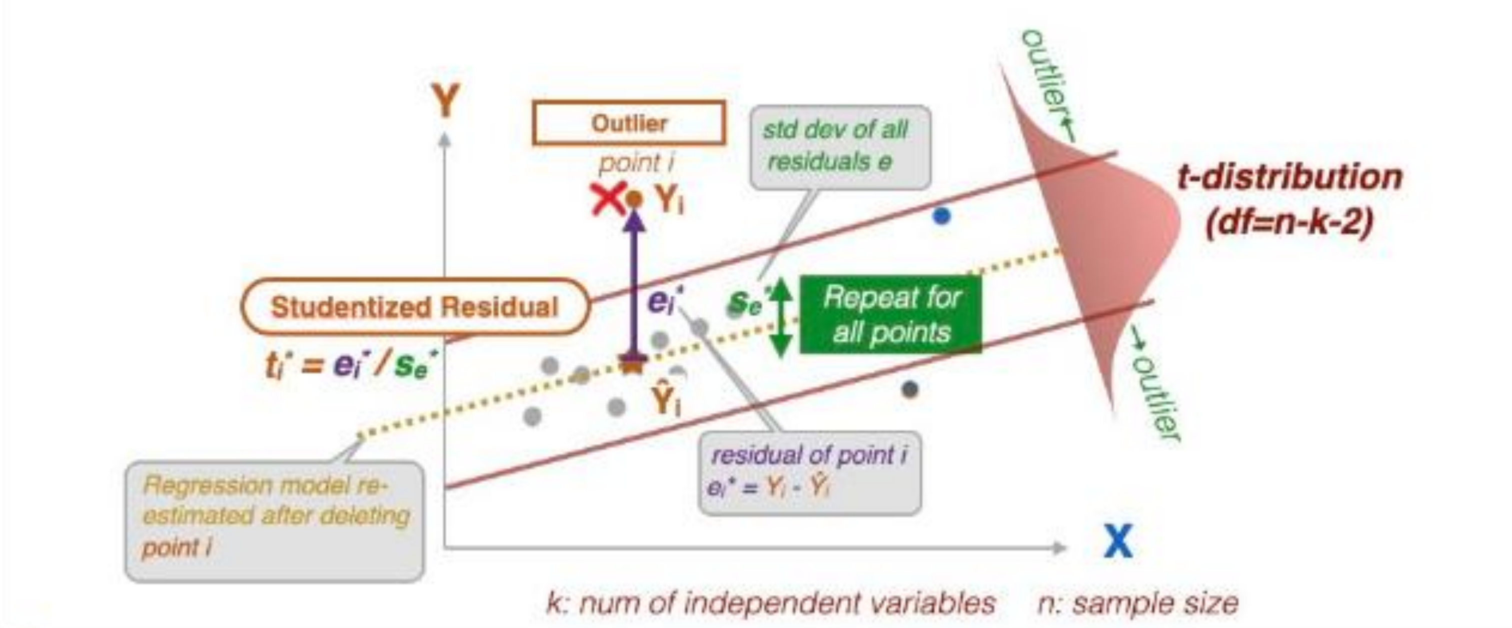
- **Methods of finding outliers**

- Sorting Datasheet to Find Outliers
- Graphing Your Data to Identify Outliers (Boxplot, Histogram)
- Using Z-scores to Detect Outliers
- Finding Outliers with Hypothesis Tests
- Studentized Residuals

Studentized residual

- To identify outliers, the preferred method is to use studentized residuals. For each data point i, the point is deleted and the regression model is re-estimated with the remaining data points. The residual of this data point is its Y-value minus the predicted Y-value from the regression. This is repeated for all the data points, and we are able to determine the standard deviation of the residuals.

Measure	Identify	Process	Criteria
Studentized residuals (t_i^*)	Outliers	$\lvert t_i^* \rvert$ is num of std dev from regression line	$\lvert t_i^* \rvert > t_{cv}$ *(df=n-k-2)* or $\lvert t_i^* \rvert > 3$



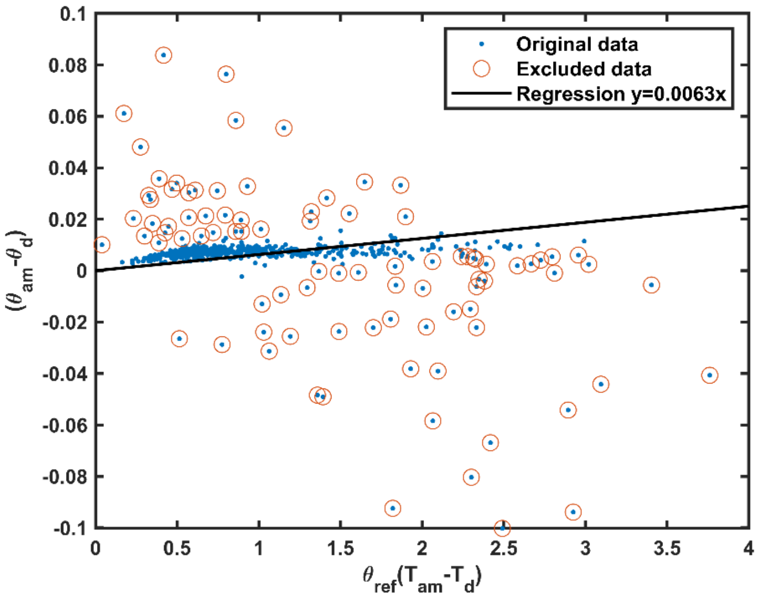
Automated temperature effects removal

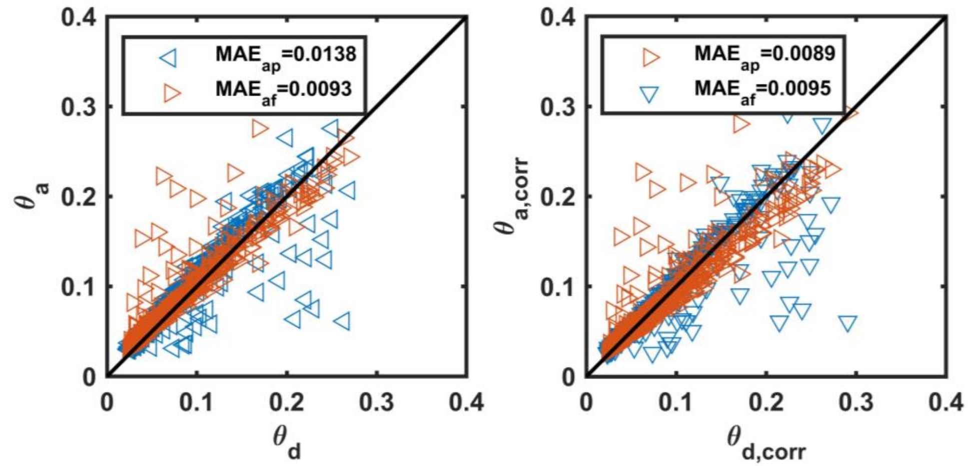
- High amplitude data points often distort the regression line by shifting it towards them, rainfall induced amplitude shifts need to be excluded from the process
- SWC is influenced by rainfall events and therefore, θ_d and $A_\theta$are as well. Hence, SWC data which correspond to rainfall events can be easily recognized.
- In statistics, the data points which scattered away from major data cloud or unusually large or small values are referred to as high and low outliers, respectively. Statistical inference methods like confidence interval and statistical tests are widely used to identify such outliers
- Many statisticians recommend using studentized residuals to detect outliers. Usually, the studentized residuals of a data set approximate a t-distribution with a known degree of freedom. By estimating the shifts from a required level of confidence in that t-distribution, outliers can be retrieved.
- $S_{ri} = \frac{y_i - \hat{y}_i}{\sqrt{MSE_{(i)}(1-h_j)}}$
- where y_i and $\hat{y}_i$ = observed and fitted amplitudes of SWC, respectively, $MSE_{(i)}$ = mean squared error of the regression fit calculated by removing observation i and h_j stands for the leverage value for observation i
- Firstly, a coefficient was estimated for the soil moisture data set (including rainy days) after filtering out the negative temperature days. Secondly, studentized residuals (Sri) were estimated by using Eq.
- Subsequently, shifts of each studentized residual from the upper 99% confidence level of the studentized residuals t- distribution were evaluated. Afterwards, the data points which correspond to shifts larger than zero were removed as outliers.

Application: Temperature effect removal

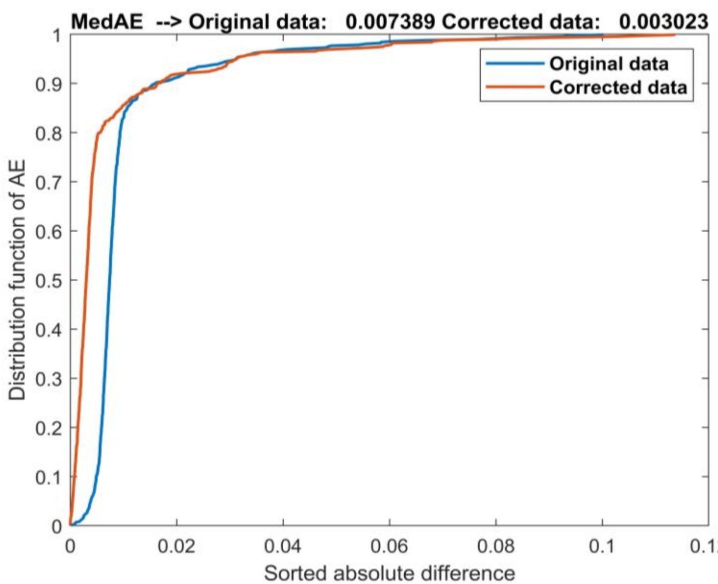
Applying newly developed method to *in-situ* data at ASC and DES time

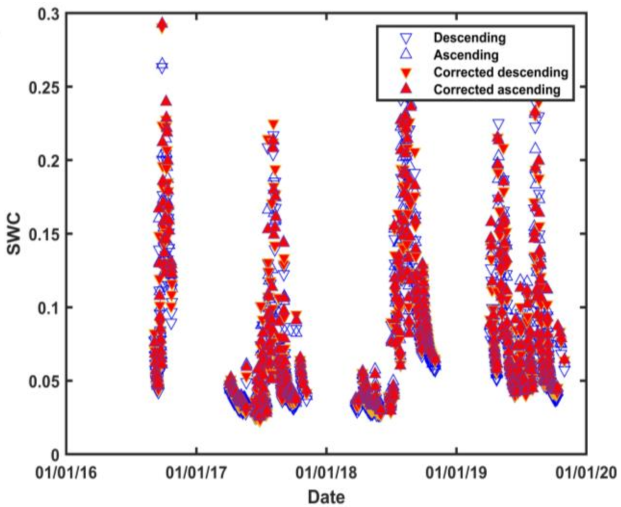
$$\theta_{asc,m} - \theta_{des} = \alpha\bar{\theta}\,(T_{asc,m} - T_{des})$$



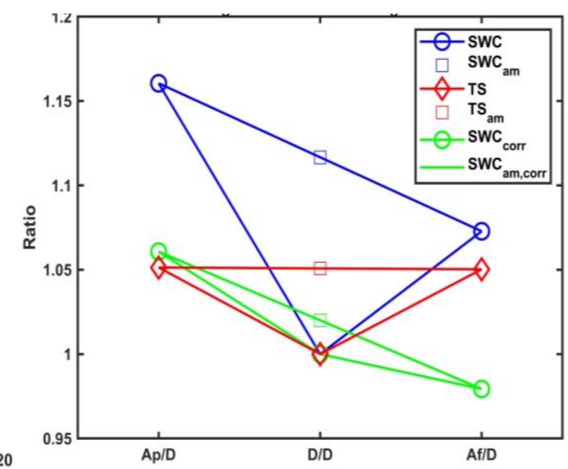


Results and effects of temperature effect error removal for *in-situ* mimic data

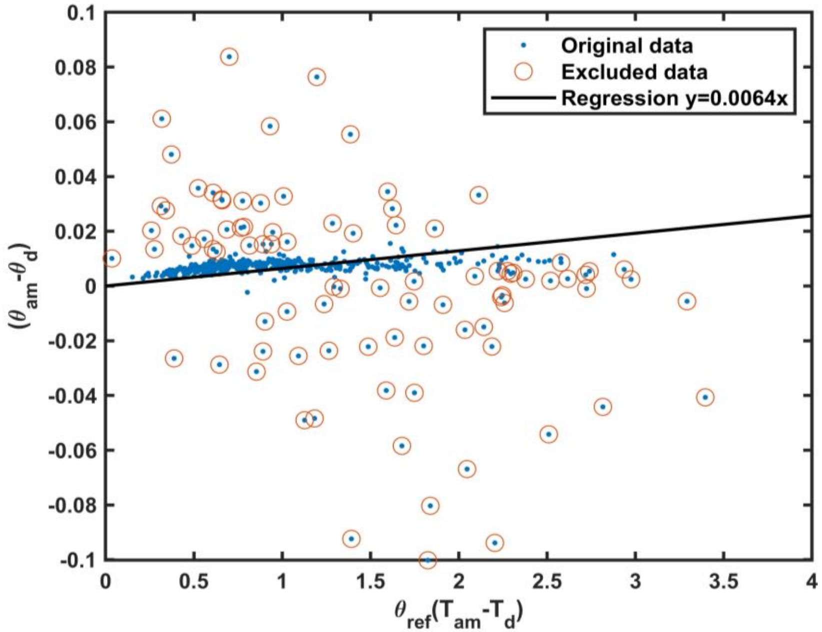


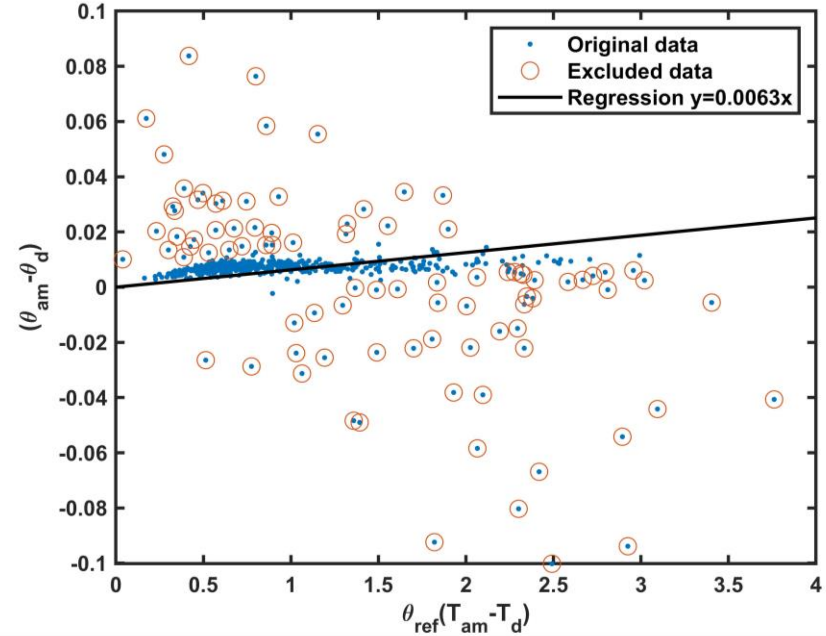


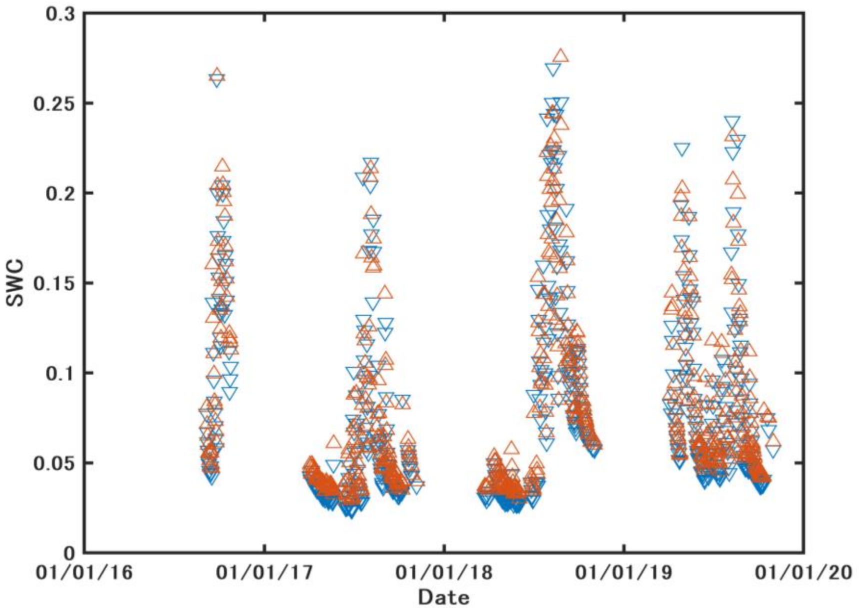
A diagram of corrected SWC ASC and DES

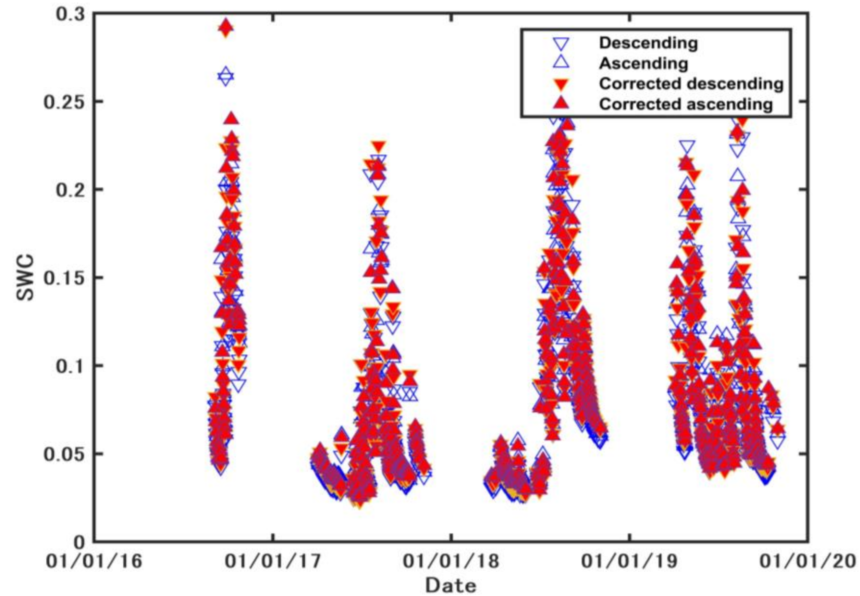


In-situ SWC data









Radiative Transfer Model of the Soil Surface–Vegetation Layer

- The low-frequency microwave radiative transfer used in soil moisture calculations is affected only slightly by the atmosphere. If these effects are ignored, the microwave brightness temperature $TB_{c,p}$ of a land surface covered uniformly by vegetation, as observed by satellites, can be expressed as follows.
- $TB_{c,p} = TB_{s,p}.e^{-\tau_c} + (1-\omega_c)(1-e^{-\tau_c})T_c + (1-\omega_c)(1-e^{-\tau_c}).T_c.\Gamma(\theta,p).e^{-\tau_c}$
- where the subscript p represents the polarization of the waves; the subscript c refers to a component related to the vegetation; $TB_{s,p}$ is the microwave brightness temperature of the soil surface; τ_c and ω_c are the optical thickness and single scattering albedo of the vegetation layer, respectively; T_c is the physical temperature of the vegetation; Γ is the Fresnel power reflectivity; and θ is the incidence angle, which is fixed at 55 ° for the AMSR-E. The first term on the right-hand side of Eq. (1) represents the radiation from the ground surface dissipated by the vegetation layer; the second and third terms represent the upward radiation from the vegetation layer itself and the reflection of the downward radiation, respectively.
- $TB_{s,p} = \left[1 - \{(1-Q).\Gamma(\theta,p) + Q.\Gamma(\theta,q)\}.e^{-h' cos^2\theta}\right].T_s$
- where T_s is the soil physical temperature, Q is the polarization mixing ratio, h' is the roughness height, and q is the opposite polarization from p. Q and h' are constants that depend on the surface roughness of the soil. Here, we define $H{=}e{-}h'cos2\theta$. Values of Q and H for each band (10 GHz and 36 GHz) can be determined by comparing the brightness temperature data observed by the AMSR-E with the in situ data at the Mongolia validation site

Satellite SM data with TB