Data Article

In situ soil moisture and temperature network in genhe watershed and saihanba area in China

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ABSTRACT

The dataset presented in this article is related to the work “Evaluation and Analysis of SMAP, AMSR2, and MEaSUREs Freeze/Thaw Products in China [1]”. Soil moisture and temperature are important variables of land-atmosphere energy exchange, monitoring vegetation growth, predicting drought disasters and climate and hydrological modelling [2–6]. This work provides detailed information on \textit{in situ} soil moisture and temperature data network established in the Genhe watershed and Saihanba area in China, respectively. The Genhe watershed represents the complex surface heterogeneity in Northeast China. Therefore, data from 22 \textit{in situ} sites were established in the Genhe watershed since March 2016 to improve the dynamic analysis and modeling of remotely sensed information for complex land surfaces. Saihanba is currently China’s largest manmade forest and has a unique alpine wetland and a complete aquatic ecosystem. There are 29 \textit{in situ} sites deployed in Saihanba since August 2018 for studying the cold temperate continental monsoon climate and es-
Cui, G.X. Wang, J.W. Yang, X.J. Liu, and X. Su, estimated forest carbon storage capacity and carbon emissions from manmade forests. Soil temperature and permittivity data in the network were measured using ECH2O EC-5TM probes (Decagon Devices, Inc., Washington, USA, https://www.metergroup.com/) and XingShiTü (XST) probes (BEIJING XST Co., Ltd., www.xingshitu.com) every 30 min at depths of 3, 5, and 10 cm for the Genhe watershed continuous automatic observation network, and depths of 5 and 10 cm for the Saihanba continuous automatic observation network. In the Genhe watershed, soil moisture and soil temperature data in the network were automatically collected using the EMS0 data collection system. The Saihanba area has the XST data collection system to record soil temperature and permittivity. The permittivity data collected with the XST data collector were transformed to soil moisture data (volumetric water content) based on the formula developed by [7]. The datasets of the Genhe watershed and Saihanba area consist of raw data acquired by the data collector and processed data of soil moisture and temperature. The Saihanba dataset also includes the calibration data based on soil texture. The result of temporal variations analysis in observed data in the Genhe Watershed and the processing in observed data in the saihanba area show that the long-term in situ soil moisture and temperature datasets can be used for the validation/calibration and improvement of the soil moisture and soil freeze/thaw algorithm.

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## Specifications table

| Subject                        | Earth-Surface Processes                                                                 |
|-------------------------------|----------------------------------------------------------------------------------------|
| **Specific subject area**     | Soil moisture and temperature, Remote Sensing, Validation.                              |
| **Type of data**              | Tables, figures.                                                                        |
| **How data were acquired**    | Soil temperature and permittivity were automatically measured using STM and XST probes. |
| **Data format**               | Raw and processed.                                                                      |
| **Parameters for data collection** | Soil moisture and temperature at the depths of 3, 5, and 10 cm for the Genhe watershed and 5 and 10 cm for the Saihanba area. |
| **Description of data collection** | Soil moisture (m³/m³) and temperature (°C) data were collected and stored using the EMS0 data logger in the Genhe watershed. Soil permittivity (dimensionless) and temperature (°C) data were collected and stored using the XST data logger in the Saihanba area. The long-term observation data of the Genhe watershed were manually exported and stored. The observation data of the Saihanba area were transferred back to the indoor wireless network server every day. |
| **Data source location**      | Genhe watershed, Inner Mongolia, China (50.16°–50.66°N, 120.5°–121.5°E)                |
|                               | Saihanba area, Hebei Province, China (42°–42.5°N, 117°–117.5°E)                         |
| **Data accessibility**        | Repository name: Mendeley Data                                                          |
|                               | Data identification number: http://dx.doi.org/10.17632/hj22ymt7xj.1                     |
|                               | Direct URL to data: https://data.mendeley.com/datasets/hj22ymt7xj/1                      |
| **Related research article**  | J. Wang, L.M. Jiang, H.Z. Cui, G.X. Wang, J.W. Yang, X.J. Liu, and X. Su,               |
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|                               | https://doi.org/10.1016/j.rse.2020.111734.                                               |
Value of the Data

- The dataset can provide ground truth of soil moisture and soil freeze/thaw spatial scales as evaluation or calibration of soil moisture and freeze/thaw estimates from microwave remote sensing and land hydrological modeling at regional scales.
- This dataset is beneficial to study the land surface and atmosphere interactions and climate change and water cycle on a regional scale.
- The dataset can be further used to optimize the distribution of sites by analyzing the representativeness of the data collected at those sites and to obtain high-quality observations at low cost.
- The dataset complements the existing ground observations in China.

Data Description

The dataset contains raw data and processed data collected from the Genhe watershed and the Saihanba area. All the data are stored in a ZIP archive. The data file of each automatic observation network is named with the site name and the data level. The observed variables and data profiles at each site in the Genhe watershed and Saihanba area are shown in Table 1. There are three depth measurements (3, 5, and 10 cm) in the Genhe watershed and two (5 and 10 cm) in Saihanba. In Table 1, field names such as Soil_moisture_5 and Soil_temperature_5 mean the measurements of soil moisture and soil temperature at the depth of 5 cm below the surface in the observational network. The raw data are soil temperature and permittivity for the Saihanba area and soil moisture and soil temperature for the Genhe watershed, respectively.

According to the sensor specifications, the accuracy of soil temperature and soil moisture observations in the Genhe watershed taken with the EC-5TM probes are 1°C and 2–3%, respectively. The accuracy of soil temperature and soil moisture observations in Saihanba area taken with the XST probes are 0.5°C and 3%, respectively. The data that could not be collected are marked as NaN. There are four sites (A8, A10, A12, and P4) with data collection failure, five sites (A2, A4, P1, P3, and P5) with data collection failure during winter, and one site (P10) with data collection failure at 10 cm depth in Saihanba.

Experimental Design, Materials, and Methods

Automatic observation network design and data acquisition method

Genhe Watershed Observation Network

The Genhe watershed has a cold and humid temperate forest climate and a continental monsoon climate. It is located in northern Inner Mongolia on the western slope of the northern Greater Khingan Range. This region has hills with gentle slopes (slopes of less than 15 degrees occupy 80% of the area) and a mean altitude of approximately 800 m. The overall geomorphology is represented by quasi-flat ground and rounded mountains with flat tops at similar altitudes [8,9]. Because of its significant geographical location, the Genhe watershed provides a representative coverage of the complex land surface and hydrometeorological conditions in Northeast China. Therefore, the in situ soil moisture and temperature observed network was conducted in the Genhe watershed to improve the dynamic analysis and remote sensing modeling of surface parameters, including soil moisture and surface frozen/thaw status [1,9]. In addition, the dataset would provide the surface condition to the regional biomass and carbon fluxes estimation of forest vegetation in Northeast China.

The Genhe Watershed Observation Network has been operated on both sides of the Genhe watershed (50.16°–50.66°N, 120.5°–121°E) since October 2013 (7 sites), and the number of available sites was gradually increased to 22 from October 2015 to May 2017. There are four (site
1–site 3 and site 5), one (site 9), three (sites 11, 12, and 14), nine (site 15–20, 22, 24, and 26), and five (site 21, 23, 27–29) sites that have been collecting data successfully since October 2013, April 2015, October 2015, September 2016, and May 2017, respectively. Therefore, to ensure the validity of the dataset, we only provide the data with continuity and integrity and the description of observation sites from March 2016 to February 2018. The detailed information on the sites is presented in Fig. 1 and Table 2. The land cover map in Fig. 1 is from the National Geomatics Center of China (GlobeLand30-2010, http://glc30.tianditu.com).

The Genhe Watershed features forests, shrubland, grassland, and cultivated land. The soil texture is silt (50–54%), sand (6–9%), clay (39–44%), and organic matter (7–8%). The site of the Genhe Watershed Observation Network is equipped with the EM50 data collection system with EC-5TM probes. Soil temperature and moisture were measured every 30 min at depths of 3, 5, and 10 cm below the surface at each site. The raw data obtained using the probes are collected and stored by the data collection system, and the time series of data are stored manually from the data collection system.

To ensure the reliability of the Genhe Watershed observation data, this work evaluated the relationship between soil moisture, soil temperature, and precipitation time series (Fig. 2) (precipitation data from the China Meteorological Data Service Center, http://data.cma.cn/). Fig. 2 (a) shows that the seasonal variations in soil moisture at depths of 3, 5, and 10 cm are similar, and the fluctuations in soil moisture at different depths within a day are not obvious. Soil moisture at three depths increases with precipitation. As the frequency of rainfall increases, soil moisture at three depths varies significantly and show an obvious stratification. Overall, the response of soil moisture to precipitation is relatively sensitive. Fig. 2 (a) shows that temporal variations in soil temperature at the depths of 3, 5, and 10 cm are similar. From January to March and from mid-October to December, surface temperature is below 0°C and the soil is frozen. When the soil is frozen, the soil moisture value remains relatively stable without significant changes. At the beginning of April, soil temperature increases above 0°C, the frozen soil begins to melt,
and soil moisture gradually increases. This result is consistent with the local climate patterns. With outlier filtering, this dataset meets the requirements of data accuracy for the soil moisture retrieval algorithm development and satellite soil moisture product validation.

**Saihanba Observation Network**

The Saihanba area is located in the transition zone from Yanshan Mountain to Inner Mongolia, with an elevation of 1100–1800 m and a semi-arid and semi-humid climate. As the source of the Luan River, Saihanba is a key area for global change research [10]. The soil of this area is composed of silt (12%), sand (79%), and clay (9%). With complex climate conditions and large spatial heterogeneity of soil moisture and temperature within the satellite radiometer coarse pixels of 10–50 km, sparse meteorological observation sites cannot reflect the spatial distribution of soil moisture and temperature in Saihanba. Therefore, it is important to set up a soil temperature and moisture observation network at the microwave pixel scale over the Saihanba area. The Saihanba soil temperature and moisture automatic observation network (42°–42.5°N, 117°–117.5°E) measures data both at the passive microwave pixel scale (e.g., SMAP, SMOS, AMSR2, and FY-3B) and active microwave satellite pixel scale (e.g., Sentinel-1). The observation area of the active and passive microwave pixels is 0.1° × 0.1° and 0.25° × 0.25°, respectively. There are 12 sites (named hereafter A (Active)) in active microwave pixels and 17 sites (named hereafter P (Passive)) in passive microwave pixels. The distribution of automatic observation sites is shown in Fig. 3. The land cover map is from GlobeLand30-2010 as in Fig. 1. The detailed geographical location and data availability time window at each site are shown in Table 3. Each site is

| Site name | Longitude (deg.) | Latitude (deg.) | Altitude (m) | Land cover | Data available time (Month/Day/Year) |
|-----------|------------------|-----------------|--------------|------------|-------------------------------------|
| Site 1    | 120.522          | 50.505          | 705          | Grass      | 10/07/2013–02/28/2018               |
| Site 2    | 120.711          | 50.451          | 699          | Larix gmelinii | 10/10/2013–02/28/2018              |
| Site 3    | 120.840          | 50.450          | 628          | Shrub, birch forest | 10/06/2013–02/28/2018              |
| Site 4    | 120.525          | 50.426          | 608          | Grass, Shrub | 10/07/2013–03/31/2014               |
| Site 5    | 120.531          | 50.413          | 628          | Grass, Shrub | 10/07/2013–02/28/2018               |
| Site 6    | 120.533          | 50.412          | 673          | Grass      | 10/07/2013–10/09/2015               |
| Site 7    | 120.539          | 50.415          | 792          | Grass      | 10/07/2013–09/19/2015               |
| Site 8    | 120.575          | 50.509          | 738          | Birch forest | 09/26/2014–04/22/2015               |
| Site 9    | 120.876          | 50.565          | 705          | Birch forest | 04/21/2015–02/28/2018               |
| Site 10   | 120.954          | 50.555          | 728          | Larix gmelinii | 04/21/2015–10/02/2015              |
| Site 11   | 120.836          | 50.300          | 724          | Shrub, Birch forest | 10/10/2015–02/28/2018              |
| Site 12   | 120.883          | 50.367          | 651          | Shrub, Birches | 10/10/2015–02/28/2018              |
| Site 13   | 120.761          | 50.364          | 754          | Birch forest | 10/10/2015–05/10/2017               |
| Site 14   | 120.581          | 50.511          | 731          | Birch forest | 10/09/2015–02/28/2018               |
| Site 15   | 120.843          | 50.575          | 730          | Larix gmelinii, Birches | 09/22/2016–02/28/2018              |
| Site 16   | 120.926          | 50.492          | 763          | Birch forest | 09/22/2016–02/28/2018               |
| Site 17   | 120.987          | 50.451          | 640          | Grass, Shrub | 09/23/2016–02/28/2018               |
| Site 18   | 120.484          | 50.327          | 608          | Crop       | 09/24/2016–02/28/2018               |
| Site 19   | 120.696          | 50.329          | 644          | Shrub, Birches | 09/24/2016–02/28/2018              |
| Site 20   | 120.589          | 50.310          | 714          | Grass, Birches | 09/25/2016–02/28/2018              |
| Site 21   | 120.586          | 50.220          | 731          | Grass      | 05/14/2017–02/28/2018               |
| Site 22   | 120.499          | 50.209          | 654          | Crop       | 09/24/2016–02/28/2018               |
| Site 23   | 120.675          | 50.223          | 754          | Grass, Birches | 05/12/2017–02/28/2018              |
| Site 24   | 120.927          | 50.309          | 668          | Grass      | 09/25/2016–02/28/2018               |
| Site 25   | 120.904          | 50.344          | 681          | Grass, Birches | 09/25/2016–05/10/2017             |
| Site 26   | 120.948          | 50.257          | 691          | Grass      | 09/25/2016–02/28/2018               |
| Site 27   | 120.510          | 50.530          | 788          | Birch forest | 05/09/2017–02/28/2018              |
| Site 28   | 120.537          | 50.463          | 641          | Grass, Shrub | 05/09/2017–02/28/2018              |
| Site 29   | 120.977          | 50.340          | 802          | birch forest | 05/15/2017–02/28/2018              |
Fig. 2. Temporal variations in observed data in the Genhe Watershed Observation Network (a: soil moisture and precipitation; b: soil temperature).

Fig. 3. Distribution of sites in Saihanba observation network.

equipped with the XST data collection system. In active and passive microwave pixels, XST and 5TM probes are used to measure soil temperature and permittivity at each site, respectively. One site in the passive microwave pixel (P5) also belongs to the active microwave pixel, and both XST (P5_XST) and 5TM (P5_5TM) probes are buried. At each station, two probes are used to measure soil temperature and permittivity. The two probes are horizontally inserted at 5 and 10 cm depths. The XST data loggers supplied by two dry batteries record data every 30 min and can keep working for more than one year. Same as the automatic observation network in the Genhe watershed, to prevent the rainwater damage to the data collector, the XST data loggers
are sealed with a self-sealing bag. The raw soil temperature and permittivity data are measured at 5 and 10 cm depths below the surface and transformed back to the indoor server daily using a data transmission device.

In order to ensure the authenticity of the observation data, we collected soil samples and used the soil texture data to calibrate the soil moisture data in Saihanba. The field soil samples were collected horizontally using a ring cutter with a volume of 100 mL and diameter of 5 cm (Fig. 4). The ring cutter’s center corresponds to the measured depth (−5 cm, −10 cm) while collecting the soil samples. Soil permittivity data, recorded using the probes, were converted into the volumetric water content (W) using the formula developed by [7] (Eq. 1). The volumetric water content of the soil samples collected at each site was obtained in the laboratory using a drying box at 105°C for 24 h. Then, the linear relationship between the volumetric water content of soil samples and probes was used to calibrate the soil moisture observed by XST.

**Data processing**

The raw data stored using the EM50 data logger included soil moisture and temperature data in the Genhe watershed, while the raw data collected with the XST data logger were soil permittivity and temperature data in the Saihanba area. Permittivity was converted to the volumetric water content (W) using Eq. (1).

\[
W = 4.3 \times 10^{-6} \cdot \varepsilon^3 - 5.5 \times 10^{-4} \cdot \varepsilon^2 + 2.92 \times 10^{-2} \cdot \varepsilon - 5.3 \times 10^{-2}
\]  

(1)

where \( \varepsilon \) is the measured soil permittivity.
Fig. 4. Soil sample collection with a ring cutter.

Fig. 5. Relationship between the volumetric water content (W) calculated using soil samples and measured with the sensors over Saihanba area.

The observation data of the Genhe watershed are composed of level 0 (L0) and level 1 (L1) data, and the observation data of Saihanba are composed of L0, L1, and level 2 (L2) in the Microsoft Excel format. L0 data are the raw observation data of surface parameters taken every 30 min in the Excel format. L1 data are the valid soil temperature and moisture data taken every 30 min in the Excel format. L2 data of Saihanba are L1 soil temperature data and calibrated soil moisture data obtained by calibrating the L1 soil moisture data using the linear calibration equation in the Excel format. Fig. 5 shows the relationship between the volumetric water content calculated using the soil samples and measured with sensors over the Saihanba area.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

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