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Monthly Drought Index (1951–2016) and 8-day Frequency Soil Moisture (2007–2016) Dataset in Southwest China

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Abstract: The self-calibrating Palmer Drought Severity Index (scPDSI) dataset was developed based on the concept of water balance, and represents an appropriate index for comparing the relative spatiotemporal variability of the dryness/wetness across southwest of China impacted by climate warming. The temporal variation characteristics of the dryness/wetness in southwest of China and the response of soil moisture were analyzed based on the scPDSI dataset and the European Space Agency (ESA) Climate Change Initiative (CCI) remotely sensed soil moisture. The dataset is consisted of the following data in southwest of China: (1) monthly scPDSI during 1951–2016; (2) 8-day frequency active microwave remote sensing soil moisture data during 2007–2016; and (3) 8-day frequency standardized CCI soil moisture data during 2007–2016. The data spatial resolution is 0.5°. The dataset consists of two data files and are archived in . xls and. tif data formats with data size of 98 KB (compressed to one single data file with 31.7 KB).

Keywords: drought severity index; soil moisture; dryness/wetness; Southwest China

Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2020.04.17.V1.

1 Introduction

Southwest China includes provinces of Sichuan, Yunnan, Guizhou, Guangxi Zhuang autonomous region and Chongqing municipality with a total land area of 1,362,300 km^2. Southwest China is affected by the East Asian monsoon and the South Asia tropical monsoon, and the climate types are diverse. The regional climate is also greatly affected by local factors, e.g. the topography. As the global climate is significantly warming, the regional cli-

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[2] Hu, G. C., Zhou, J., Lu, J., *et al*. Monthly drought index (1951–2016) and 8-day frequency soil moisture (2007–2016) dataset in Southwest China [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2020. https://doi.org/10.3974/geodb.2020.04.17.V1.

mate tends to be warm and dry in Southwest China. In the context of significant global warming, droughts in southwest of China have been frequent in recent years, such as the severe drought in Sichuan and Chongqing in the summer of 2006, the drought in southwest of China in the autumn of 2009 to the spring of 2010, and the mid summer and autumn drought across southwest of China in 2011.

With the development of meteorology and related disciplines, dozens of quantitative indicators that reflect changes in climate dryness/wetness have been developed in climate change and drought monitoring studies, such as the single factor indices that rely only on precipitation, the indices that combine precipitation and temperature factors, and the index based on satellite remote sensing technology, etc. Commonly used indices include Precipitation Anomaly Percentage (PAP), Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI)[1], and Palmer Drought Severity Index (PDSI), etc. The PAP and SPI are mainly based on long-term series of precipitation data, and have certain limitations in reflecting the change of dryness/wetness conditions under the background of climate warming. The SPEI and PDSI consider the effects of precipitation and evapotranspiration on water balance, and the PDSI comprehensively reflects the effects of precipitation and evapotranspiration based on the soil water balance equation. The self-calibrating PDSI (scPDSI) with explicit physical meaning was derived through the continuous correction and improvement[2]. Therefore, the temporal variation of dryness/wetness over southwest of China under the background of climate warming was analyzed using the scPDSI dataset in 1951–2016 , and the response of surface soil moisture was analyzed using the standardized European Space Agency (ESA) Climate Change Initiative (CCI) soil moisture dataset in 2007–2016, to provide a scientific basis for systematic analysis of the spatiotemporal evolution of climate in southwest of China and for the monitoring and assessment of drought disasters.

2 Metadata of the Dataset

The metadata of the “Monthly drought index (1951–2016) and 8-day frequency soil moisture (2007–2016) dataset in southwest of China”[3] is summarized in Table 1. It includes the dataset full name, short name, authors, year of the dataset, temporal resolution, spatial resolution, data format, data size, data files, data publisher, and data sharing policy, etc.

3 Methods

3.1 Data Collection

The PDSI is a commonly used indicator to reflect changes in climate dryness/wetness, and is widely used in hydrology, meteorology, and agriculture. The PDSI is based on the principle of soil water balance to characterize the prolonged water deficiency (or excess) situation in which the actual water supply is continuously less (or more) than the local water supply at a normal level over a period of time. The PDSI is a function of water anomaly (deficiency or excess) and a duration index. The water balance is calculated by considering the difference of water supply and demand in the previous period, and can reflect large-scale soil moisture dynamics. Due to the influence of the previous duration index, the time scale of climate change in dryness/wetness characterized by PDSI is usually 9–12 months, which can reduce the short-term local climate fluctuations. The PDSI is related to local climate background, whereas the scPDSI corrects the climate weighting factor and duration index, overcomes the limitations of PDSI to account for water deficiency (or excess) in different regions and at different times[2]. After standardization, the scPDSI values generally vary between –5 (Drought) and +5 (Moist) (Table 2).

Table 1 Metadata summary of the "Monthly drought index (1951–2016) and 8-day frequency soil moisture (2007–2016) dataset in Southwest China"

Items	Description
Dataset full name	Monthly drought index (1951–2016) and 8-day frequency soil moisture (2007–2016) dataset in Southwest China
Dataset short name	scPDSI(1951-2016)_CCI-SoilMoisture(2007-2016)_SW_China
Authors	Hu, G. C. L-6160-2016, Aerospace Information Research Institute, Chinese Academy of Sciences, hugc@aircas.ac.cn Zhou, J. G-6760-2011, College of Urban and Environmental Science, Central China Normal University, zhou.j@mail.ccnu.edu.cn Lu, J. L-4754-2016, Aerospace Information Research Institute, Chinese Academy of Sciences, lujing@aircas.ac.cn Zheng, C. L. L-6182-2016, Aerospace Information Research Institute, Chinese Academy of Sciences, zhengcl@aircas.ac.cn Jia, L. I-1457-2014, Aerospace Information Research Institute, Chinese Academy of Sciences, jiali@aircas.ac.cn
Geographical region	Southwest of China: 21°9′N–34°19′N, 97°20′E–112°2′E
Year	1951–2016
Temporal resolution	Monthly, 8-day
Spatial resolution	0.5°
Data format	.tif, .xls
Data size	98 KB
Data files	(1) scPDSI(1951-2016)_CCI-SoilMoisture(2007-2016)_SW_China (Table 1: monthly scPDSI during 1951–2016) (2) scPDSI(1951-2016)_CCI-SoilMoisture(2007-2016)_SW_China (Tble 2: 8-day frequency active microwave remote sensing soil moisture data during 2007–2016) (3) scPDSI_1951-2016_interannual_slope_SW_China (8-day frequency standardized CCI soil moisture data during 2007–2016)
Foundation(s)	Ministry of Science and Technology of P. R. China (2017YFD0300402); National Natural Science Foundation of China (41701495)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing &Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[4]
Communication and searchable system	DOI, DCI, CSCD, WDS/ISC, GEOSS, China GEOSS, Crossref

The global scPDSI dataset used in the study was derived from the Climatic Research Unit (CRU), University of East Anglia[5]. The time range covers 1901–2016 at a 0.5°spatial resolution and a 1 month temporal resolution. The precipitation and potential evapotranspiration data for the scPDSI water balance model were derived from the version 3.25 CRU time-series (TS) global high-resolution grids of monthly climatic observations[6]. The potential evapotranspiration was estimated on monthly basis based on the Penman–Monteith equation taking accounts of both temperature and radiation. The CRU scPDSI data has good responsiveness to changes in climate dryness/wetness and has been used for the monitoring and assessment of global droughts[7]. The CRU TS meteorological observations were derived based on the interpolation of meteorological station observations. Since the more complete station observations in China began in the early 1950s, in this study the 1951–2016 CRU scPDSI dataset were used for the analysis of temporal variation of dryness/wetness over southwest of China.

Table 2 Levels of Dryness/Wetness Defined by Ranges of self-calibrating Palmer Drought Severity Index (scPDSI)

scPDSI	Dryness/Wetness
> 4	Extremely Moist
3–4	Very Moist
2–3	Unusually Moist
1–2	Slightly Moist
–1–1	**Near Normal**
–2– –1	Pre-Drought
–3– –2	Moderate Drought
–4– –3	Severe Drought
< –4	Extreme Drought

The global satellite observed ESA CCI soil moisture product combines various single-sensor active and passive microwave soil moisture products into three harmonised products: ACTIVE, PASSIVE and COMBINED[8]. The version 4.2 ESA CCI soil moisture data has a spatiotemporal resolution of 0.25°/1-d and spans a long-time range of 1979–2016. For southwest of China with a humid climate and dense vegetation coverage, the active microwave soil moisture data is better than the passive microwave data, and there are many gaps in soil moisture retrieved by passive microwave remote sensing in southwest of China. Therefore, in this study the ESA CCI active microwave soil moisture data since 2007 (blending the Advanced SCATterometer (ASCAT) data) was standardized and used to analyze the response of soil moisture to temporal variation of climate dryness/wetness.

3.2 Data Processing

The linear trend analysis was conducted for the annual-average scPDSI within the 1951–2016 time periods. The trend of inter-annual variation of dryness/wetness, i.e. inter-annual change rate of scPDSI, was derived based on the least squares method for the past 66 years. The positive linear trend of scPDSI indicates that the scPDSI is gradually increasing, and the climate tends to be moister. The negative linear trend of scPDSI indicates that the scPDSI is gradually decreasing, and the climate tends to be more arid.

The ESA CCI active microwave remotely sensed soil moisture is dimensionless, with values ranging from 0% to 100%. In order to compare the scPDSI and ESA CCI soil moisture, the ESA CCI soil moisture was standardized (Equation 1) with the same range of values as scPDSI.

$$SM\_S_{\mathrm{i}} = \frac{SM_{\mathrm{i}} - SM_{\mathrm{Mean}}}{\sigma} \tag{1}$$

where SM_S_{i} (dimensionless) is the standardized ESA CCI soil moisture (i is 2007, 2008, ..., 2016), SM_{i} (%) is the original ESA CCI soil moisture, SM_{Mean} (%) is the average multi-annual soil moisture for 2007–2016, and σ (%) is the standard deviation of the SM_{i} time series.

4 Data Results and Validation

4.1 Data Composition

The dataset is consisted of the following data: (1) monthly scPDSI during 1951–2016; (2) 8-day frequency active microwave remote sensing soil moisture data during 2007–2016; and (3) 8-day frequency standardized CCI soil moisture data during 2007–2016. The spatial data resolution is 0.5°. The dataset consists of two data files and archived in .xls and .tif formats with data size of 98 KB (compressed to one single data file with 31.7 KB).

4.2 Data Results and Analysis

4.2.1 Inter-annual Variation of Dryness/Wetness and the Response of Soil Moisture

The spatial distribution characteristics of the inter-annual variation trend of the scPDSI across southwest of China from 1951 to 2016 are shown in Figure 1. Most of the southwest of China has been in aridification trend in the past 66 years, and the progressive aridification trend is obvious in the border areas of Sichuan, Guizhou and Yunnan. The Tibetan Plateau in northwestern Sichuan showed a trend of humidification.

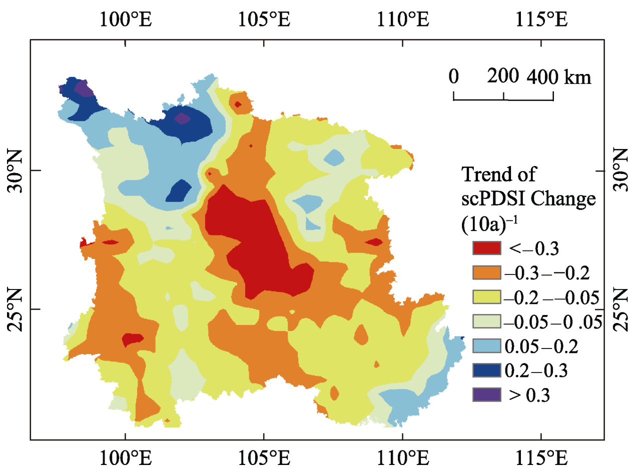

Figure 1 Pixel-based dryness/wetness trends across southwest of China from 1951 to 2016

The regional average of the annual scPDSI in southwest of China from 1951 to 2016 is shown in Figure 2. In the second half of the 20th century, the climate across southwest of China changed alternately, but the overall inter-annual trend was relatively stable. Since the 21st century, the climatic aridification trend has been very obvious, especially for the long-term continuous drought conditions in 2005–2007 and 2009–2013, mainly due to the lack of the intersection of north–south airflow in southwest of China, and due to the decreased water vapor transport from the Bay of Bengal and the South China Sea to southwest of China. In addition, when the drought occurred, the arid climate continued to spread due to the corresponding abnormal convective downdrafts, leading to less rising motion conditions to form precipitation.

The regional average of the annual scPDSI and the standardized ESA CCI soil moisture in southwest of China from 2007 to 2016 are shown in Figure 3. The overall inter-annual trend of scPDSI and standardized CCI soil moisture is consistent, indicating the transition from the early arid climate to the later humid climate. Since the time scale represented by the scPDSI is usually 9–12 months, the inter-annual variation is relatively flat and lagging, while the temporal variation of CCI surface soil moisture (in the upper 10 cm of soil) is more sensitive. For the continuous drought conditions in southwest of China from the fall of 2009 to the spring of 2010, scPDSI reflected the most arid climate in 2010, while the indication on the CCI soil moisture was not obvious, and the details of the local climate change will be analyzed by the seasonal changes in the next section.

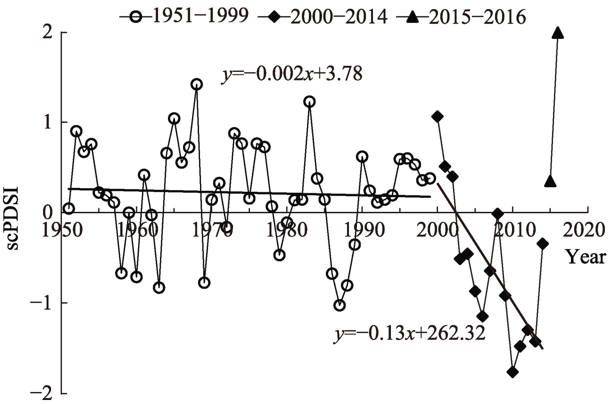

Figure 2 The inter-annual variations of the dryness/wetness indicated by scPDSI in Southwest China from 1951 to 2016

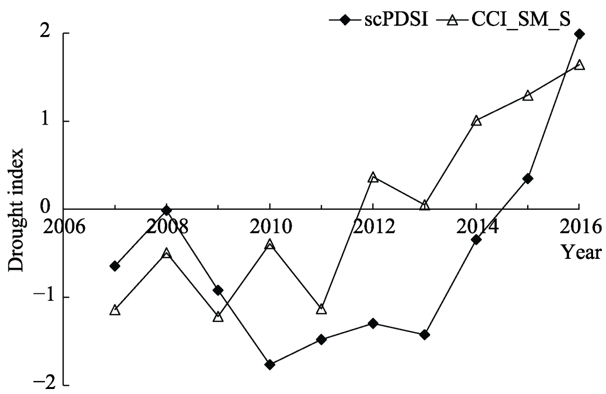

Figure 3 The inter-annual variations of the dryness/wetness indicated by scPDSI and standardized CCI soil moisture (CCI_SM_S) in southwest of China from 2007 to 2016

4.2.2 Seasonal Variation of Dryness/Wetness and the Response of Soil Moisture

The regional average of monthly scPDSI and 8 d averaged CCI soil moisture in southwest of China during the arid climate in 2009–2011 and the humid climate in 2014–2016 are respectively shown in Figure 4 and Figure 5. The multi-year average of CCI soil moisture is the average of 2007–2016 for a certain period at 8-day interval of the year to derive the standardized soil moisture. In 2009–2011, scPDSI reflected two extreme drought events, i.e., from autumn 2009 to spring 2010 and summer 2011. The CCI soil moisture in the corresponding period was significantly lower than the multi-year average. The minimum standardized CCI soil moisture reached –2, and the trough shape was consistent with scPDSI. In the second half of 2010, the drought eased and the scPDSI increased slowly, while the standardized CCI soil moisture increased rapidly to near 0, which was mainly determined by the different drought scales represented by these two indicators. For drought, it is characterized by multi-scale phenomenon. The drought scale represented by scPDSI is usually 9–12 months, reflecting the long-term hydrological drought, whereas the standardized CCI soil moisture can be used to evaluate the short-term meteorological drought and agricultural drought.

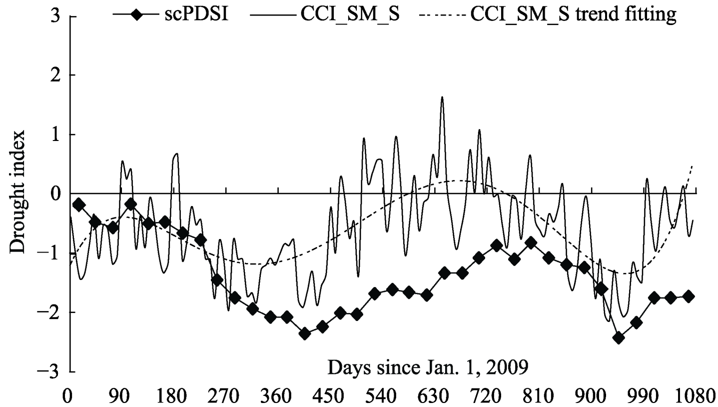

Figure 4 Seasonal variations of the dryness/wetness indicated by scPDSI and standardized CCI soil moisture (CCI_SM_S) in Southwest of China from 2009 to 2011

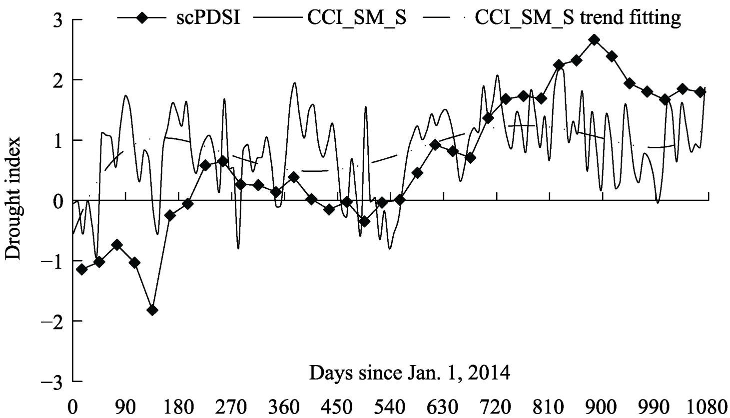

Figure 5 Seasonal variations of the dryness/wetness indicated by scPDSI and standardized CCI soil moisture (CCI_SM_S) in Southwest of China from 2014 to 2016

In 2014–2016 when the Super El Niño event occurred, scPDSI gradually turned from negative to positive, and the climate was moist. From the summer of 2015 to 2016, the climate was characterized by unusual moist, and the CCI soil moisture in the corresponding period was significantly higher than the multi-year average, the standardized CCI soil moisture is greater than 0. Therefore, the CCI active microwave soil moisture can better reflect the change of climate dryness and wetness, and also realize the large-scale indirect validation of remotely sensed soil moisture with a coarse resolution. It should be noted that the response of standardized CCI soil moisture to extreme precipitation events is not sensitive enough, and the peak shape in summer 2016 is lower than that of scPDSI. The main reason is that a large amount of precipitation forms surface runoff or infiltration to recharge groundwater during extreme precipitation events, so the change of surface soil moisture is relatively gentle.

4.3 Data Validation

The wetness index calculated from meteorological observations during 1961–2011 show that the climate in southwest of China has a trend of "warm and dry" in recent 50 years, and the trend has been further intensified since the 21st century[9–10], which is consistent with the characteristics of climate change reflected by the scPDSI. In addition, based on the soil moisture simulated by Noah land surface model from the Global Land Data Assimilation System (GLDAS), the correlation analysis of soil moisture with precipitation and air temperature shows that the correlation between surface soil moisture and temperature in southwest of China is higher than that of precipitation. The annual precipitation in southwest of China showed no significant increase trend from 1979 to 2017, and the annual average temperature showed a significant upward trend (i.e. an increasing trend in potential evapotranspiration), while the surface soil moisture showed a significant decrease trend[11]. The response of GLDAS soil moisture to the characteristics of warm and dry climate change in southwest of China, is consistent with the response of CCI remotely sensed surface soil moisture to climate change.

5 Discussion and Conclusion

The scPDSI has good responsiveness to the changes of climate dryness and wetness in southwest of China from 1951 to 2016 under the background of climate warming. The scPDSI is usually established based on meteorological data. With the time series of remotely sensed precipitation products gradually extend and accumulate, they can be applied to the establishment of the drought indicators based on precipitation[12]. In addition, the Vegetation Health Index (VHI) and Normalized Drought Anomaly Index (NDAI) established based on multi-source remote sensing data, usually have higher spatial resolution and can indirectly reflect the change of surface dryness and wetness[13–14].

The temporal variation of climate dryness/wetness over southwest of China under the background of climate warming and the response of surface soil moisture were analyzed based on the scPDSI (1951–2016) and ESA CCI active microwave soil moisture data (2007–2016), and the main conclusions are as follows:

(1) scPDSI comprehensively considers the two factors affecting water deficiency (or excess) by precipitation and evapotranspiration, and has good responsiveness to climate change in dryness/wetness over southwest of China under the background of climate warming. The active microwave soil moisture can better reflect the change of climate dryness and wetness represented by scPDSI, especially the response to drought events is more sensitive than that to extreme precipitation events, and also realize the large-scale indirect validation of remotely sensed soil moisture with a coarse resolution.

(2) Most area of the southwest of China is in acidification trend, especially since the 21st century. The climatic aridification trend is very obvious, and there are long-term extreme arid climate with extensive droughts in 2005–2007 and 2009–2013.

(3) In the context of significant climate warming, extreme meteorological events in southwest of China have occurred frequently in recent years. 2010 and 2016 is respectively the most arid year and the wettest year in the past 66 years. It is necessary to further improve the monitoring and predictive capabilities for extreme drought events and extreme precipitation events over southwest of China.

Author Contributions

Jia, L. designed the algorithms of dataset. Zhou, J. and Lu, J. contributed to the data processing of scPDSI and CCI soil moisture. Hu, G. C. and Zheng, C. L. contributed to the data analysis. Jia, L. and Hu, G. C. wrote the data paper.

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