Assessment of Meteorological and Hydrological Droughts and Floods over mainland Australia based on Drought Indices

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Introduction

Climate change has led to increased droughts and floods over mainland Australia, resulting in water scarcity, excessive surplus and socioeconomic losses. Therefore, it is of great significance to comprehensively evaluate droughts and floods from the meteorological and hydrological perspective. Firstly, we determine the Standard Precipitation and Evapotranspiration Index (SPEI) by correlation analysis to represent the meteorological drought conditions. To characterize the hydrological conditions, we calculate the hydrological drought indices including Standard Runoff Index (SRI), Soil Moisture Deficit Index (SMDI), and Total Storage Deficit Index (TSDI), using the runoff and soil moisture data from the Global Land Data Assimilation System (GLDAS) and the Terrestrial Water Storage Change (TWSC) data from Gravity Recovery And Climate Experiment (GRACE) respectively.

Datasets and Study area

➢ Meteorological data

- Southern Oscillation Index (SOI) from: http://www.bom.gov.au/climate/current/soi2.shtml, spanning from Apr. 2002 to May 2020.
- SPEI 0.5° gridded data is from: http://digital.csic.es, spanning from Apr. 2002 to Dec. 2018.

➢ GLDAS data

GLDAS Noah version 2.1 monthly model with 0.25° resolution is from https://ldas.gsfc.nasa.gov/gldas/ .

➢ GRACE/GRACE-FO Data

The GRACE and GRACE-FO monthly mascon products from April 2002 to May 2020, released by the Center for Space Research at University of Texas, Austin (CSR) are available at: https://grace.jpl.nasa.gov/data/get-data/.

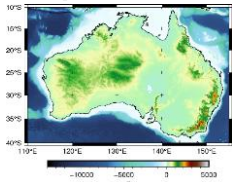

Fig.1 Terrain evaluation map of Australia mainland

Methodology

➢ Drought indices calculation

The SPI and SRI are calculated with the GLDAS Noah precipitation and runoff data respectively, based on the method of McKee *et al.* [1].

SMDI

$$\begin{cases} SD_{i,j}=\dfrac{SW_{i,j}-MSW_j}{MSW_j-MinSW_j}\times 100 \quad if\ SW_{i,j}\le MSW_j \\ SD_{i,j}=\dfrac{SW_{i,j}-MSW_j}{MaxSW_j-MSW_j}\times 100 \quad if\ SW_{i,j}> MSW_j \end{cases} \qquad \begin{cases} SMDI_1=\dfrac{SD_1}{50} \quad Initial\ value \\ SMDI_k=0.5\times SMDI_{k-1}+\dfrac{SD_k}{50} \end{cases}$$

where $SD_{i,j}$ represents the soil moisture deficit of ith year and jth month. $SW_{i,j}$ is the soil moisture variation, MSW_j, $MinSW_j$ and $MaxSW_j$ denote the median, minimum and maximum values of the soil moisture time series respectively.

TSDI & Severity

$$\begin{cases} TSD_{i,j}=TWSA_{i,j}-MTWSA_j \\ TSDI_{i,j}=\dfrac{TSD_{i,j}-\mu}{\sigma} \\ Se(t)=Me(t)\times D(t) \end{cases}$$

where $TSD_{i,j}$ denotes the Total Storage Deficit (TSD) at month jth and year ith. $MTWSA_j$ is the mean value of the TWSC series for the month jth of different years. μ is the mean of TSD and σ is the standard deviation during the study period.

Tab.1 Drought and flood grades of SPI, SPEI, SRI, SMDI and TSDI

SPI, SPEI or SRI	SMDI	TSDI	Category
2.00 or more	4.00 or more	1.60 and more	Extreme wet/ W3
1.50 to 1.99	3.00 to 3.99	1.30 to 1.59	Very wet/ W2
1.00 to 1.49	1.50 to 2.99	0.80 to 1.29	Moderate wet/ W1
0 to 0.99	0 to 1.49	0 to 0.79	Mild wet/W0
0 to -0.99	0 to -1.49	0 to -0.79	Mild dry/ D0
-1.00 to -1.49	-1.50 to -2.99	-0.80 to -1.29	Moderate dry/ D1
-1.50 to -1.99	-3.00 to 3.99	-1.30 to 1.59	Severe dry/ D2
-2.00 and less	-4.00 and less	-1.60 and less	Extreme dry / W3

Results and Analysis

➢ Temporal Analysis of Meteorological and Hydrological Droughts

- Temporal variability of SOI, SPI, SPEI and SRI, SMDI and TSDI

The correlation coefficient between SPEI and SOI is 0.47, between SPEI and SPI is 0.66, while that between SOI and SPI is only 0.37. Therefore, SPEI is determined to represent the meteorological droughts in this study.

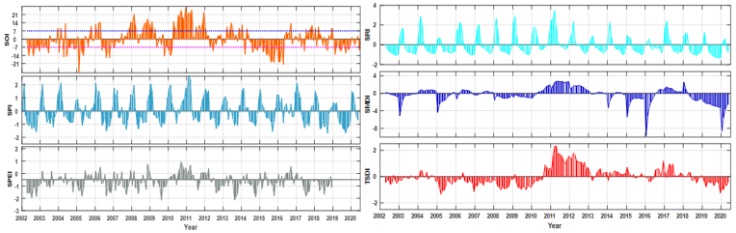

Fig.2 Temporal variability of SOI, SPI, SPEI (left) and SRI, SMDI and TSDI (right) from Apr 2002 to May 2020

- GRACE-based hydrological droughts and floods

The GRACE-based hydrological droughts and floods condition respectively represented with red and blue bars during the study period are shown in **Fig**.3 (upper) and the cumulative drought or flood severity are shown in **Fig**.3 (lower).

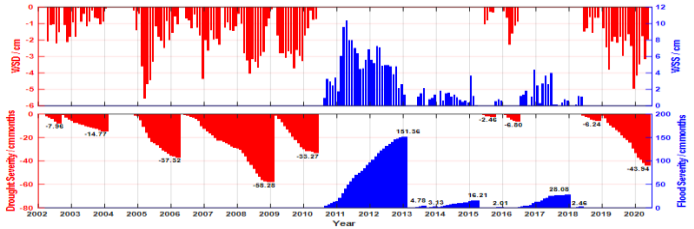

Fig.3 Duration and Severity of both Droughts and floods derived from GRACE data

➢ Meteorological and Hydrological Drought and Flood

- Classification of Meteorological and Hydrological Droughts

Based on the meteorological and hydrological indices, the drought and flood are divided into four grades, among which W0, W1, W2, and W3 represent floods in increasing order, and D0, D1, D2, D3 represent droughts with the increasing intensity.

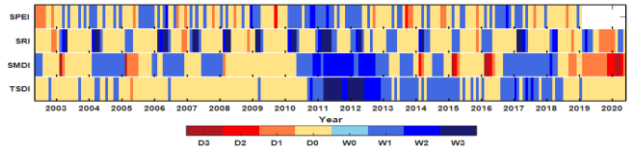

Fig.4 Meteorological and hydrological droughts of different grades over mainland Australia

- Lagging time between SPEI and hydrological drought

The lagging time between SPEI and hydrological drought indices are determined by the cross-correlation method. The correlation coefficients of SRI, SMDI and TSDI relative to SPEI are shown in **Tab**. 2 with the lagging time from 1 to 7 months.

Tab. 2 Correlation coefficients between SPEI and hydrological drought indices with lagging time from 1 to 7 months

Time lag (months)	0	1	2	3	4	5	6	7
SRI	0.42	0.43	0.39	0.26	0.09	-0.01	-0.00	-0.03
SMDI	0.13	0.21	0.26	0.42	0.41	0.39	0.37	0.34
TSDI	0.26	0.34	0.34	0.32	0.32	0.33	0.37	0.33

➢ Relationship between hydrological droughts and Indo-Pacific variability

Indian Ocean Dipole (IOD) is commonly used to measure the Sea Surface Temperature (SST) anomalies over Indian Ocean, and SOI and Niño-3.4 index is used to measure El Niño. To explore the relationships between the two hydrological droughts captured in **Fig**.3 (Drought 2006–2009 and Drought 2018–2020) and Indo-Pacific climate variability, we further use the Fourier analysis to analyze the four indices (TSDI, Nino3.4, SOI and IOD) over the periods of the two hydrological droughts. The corresponding power spectra are shown in **Fig** 5.

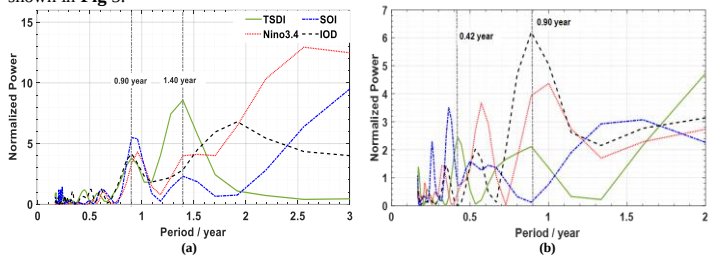

Fig.5 Power spectra of TSDI and Indo-Pacific Climate Variability indices (Nino3.4, SOI and IOD) during (a) Drought 2006–2009; (b) Drought 2018–2020.

Conclusions

- The most severe hydrological drought over mainland Australia during the study period is from May 2006 to Jan. 2009 with the drought severity of -58.28 (cm months) and the most severe flood from Jun. 2010 to Jan. 2013 is with the severity of 151.36 (cm months).
- The meteorological drought and flood are of higher frequency, while hydrological drought and flood have a relatively longer duration. And the SPEI can firstly reflect the droughts or floods over mainland Australia, and then the SRI, SMDI and TSDI reflect with the lagging time of one, three and six months, respectively.
- The results from Fourier analysis confirm that the two hydrological droughts are all related to Indo-Pacific climate variability but with slightly different driving mechanisms.

Reference: [1] McKee, T.B.; Doesken. N.J.; E.F. The relationship of drought frequency and duration to time scales. In: AMS 8th Conf. on Applied Climatology, Anaheim, California, America, 17-22 January,1993.

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