Adopting drought indices for estimating soil moisture: A North Carolina case study

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[1] Soil moisture availability has a significant impact on environmental processes of different scales. Errors in initializing soil moisture in numerical weather forecasting models tend to cause errors in short-term weather and medium range predictions. We study the use of two drought indices: Palmer Drought Severity Index (PDSI) values and Standardized Precipitation Index (SPI) for estimating soil moisture. SPI and PDSI values are compared for three climate divisions: western mountains, central piedmont, and the coastal plain in North Carolina, USA. Results suggest SPI to be more representative of short-term precipitation and soil moisture variation and hence a better indicator of soil wetness. A regression equation that uses SPI is proposed to estimate soil moisture. *INDEX TERMS:* 1866 Hydrology: Soil moisture; 1812 Hydrology: Drought; 1894 Hydrology: Instruments and techniques; 3322 Meteorology and Atmospheric Dynamics: Land/atmosphere interactions

1. Introduction

[2] Soil moisture is an important surface variable that modulates the atmospheric surface energy balance and hence has a significant impact on the vertical distribution of turbulent heat fluxes, as well as the boundary layer structure [*Alapaty et al.*, 1997]. Accurate soil moisture representation is also known to significantly enhance climate outlook projection and precipitation predictability [*Koster et al.*, 2000]. However, regionally representative soil moisture is a difficult parameter to estimate. Soil moisture measurements are limited, point-based, and show significant spatial variability. Therefore development of a simple approach for estimation of soil moisture on a regional scale is of immediate importance.

[3] Here we report the potential use of drought indices for estimating soil moisture. Two drought indices: Palmer Drought Severity Index (PDSI) and Standardized Precipitation Index (SPI) are evaluated for representing soil moisture in this study.

[4] PDSI and SPI are generally used to assess the drought conditions across the United States [*Palmer*, 1965; *Alley*, 1984; *McKee et al.*, 1993]. PDSI is defined as:

$$PDSI_i = 0.897\, PDSI_{i-1} + (1/3)z_i, \tag{1}$$

where i is the current month (period), and z_i is the difference between total precipitation and the potential evapotranspiration and runoff/recharge [*Hu et al.*, 2000]. Estimation of PDSI is based on monthly precipitation, temperature, and local "available water content" (AWC) [*Heddinghaus and Sabol*, 1991]. Despite its popularity, PDSI has several limitations as reviewed in *Alley* [1984] and *Guttman et al.* [1992]. These include an inherent time scale that reflects Palmer's study, and the uncertainty of the index to the AWC for different soil types. The Standardized Precipitation Index (SPI), proposed by *McKee et al.* [1993], is an alternative to PDSI. SPI represents a statistical z-score or the number of standard deviations (following a gamma probability distribution transformed to a normal distribution) above or below that an event is from the mean [*Edwards and McKee*, 1997]. It was designed to quantify precipitation deficit on multiple time scales and eliminate some of the disadvantages of using PDSI. One advantage of SPI is that it can be tailored to specific needs. For example, SPI are routinely calculated for 1-, 3-, and 6- month periods [*McKee et al.*, 1995]. The premise of this study is that drought indices are available and there is a potential to use them to infer regional soil moisture status, which in turn can be used for several applications including short and medium range weather predictions and for providing seasonal climate outlooks [*Pielke*, 1998; *Koster et al.*, 2000].

2. Data

[5] Precipitation data were obtained for three climate divisions (CDs) in North Carolina: divisions 1, 4, and 8 (indicated in Figure 1). The three CDs represent different land-use and topographical features (Division 1 is mountainous, 4 is semi-urban, and 8 corresponds to the coastal region). Monthly PDSI values for these CDs were obtained from the National Climatic Data Center (NCDC) and the National Drought Mitigation Center (NDMC). SPI values were obtained using the precipitation data from select stations in these regions and with the use of the method suggested by *Edwards and McKee* [1997]. Daily, weekly, biweekly, and monthly SPI were determined in an attempt to find the best fit for anomalous precipitation data sets. Precipitation anomalies were developed by removing the average precipitation amount from the individual precipitation events for the specified time period. Soil moisture observations were obtained from automated agro-meteorological towers available as a part of the North Carolina AgNet using time-domain reflectometery [*Niyogi et al.*, 1998; *Noborio*, 2001].

3. Comparing SPI, PDSI, and Precipitation Anomalies

[6] Intuitively, soil moisture values depend on precipitation amounts. However, precipitation has significant spatial variability and a co-varying factor is needed to develop the soil moisture estimates. The drought indices such as SPI and PDSI, are also dependent on the precipitation occurrence, and can be hence considered to co-vary with soil moisture.

[7] One-month SPI were calculated from 1994 to 1999 and compared with the monthly average precipitation anomalies from CDs 1, 4, and 8. Corresponding monthly PDSI values were also compared to the precipitation anomalies for the same period. These are overlaid with the CD1 SPI and precipitation anomaly time–series in Figure 2. For all the three CDs, the SPI values are in phase with the precipitation anomalies and followed the curve closely. This is expected, since SPI can be considered as a measure of precipitation anomaly; but the coherent and in-phase variations are particularly encouraging. In comparison, PDSI values, though

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