Evaporative Stress Index (ESI): A Summary

John Walz, GIS/RS Technician, GIS Training and Research Center, Idaho State University, Pocatello, ID 83209-8104

The Atmosphere Land EXchange Inverse model (ALEXI) finds the land surface energy balance from the morning rise (a four-hour period ending just before noon local time) in radiometric land surface temperature (LST), measured from the NOAA-GOES (Geostationary Operational Environmental Satellite) satellite to calculate Evaporative Stress Index (ESI). A detailed explanation of the ALEXI algorithm is given by Anderson et al. (2007a) but in essence ALEXI uses thermal-infrared (TIR) band imagery to quantify the ratio (f_{PET}) of actual evapotranspiration (ET) to potential evapotranspiration (PET). Anderson et al. (2015) found a strong correlation between ESI and verified precipitation patterns for both forested and agricultural land as well as a strong temporal and spatial correlation with the Palmer Drought Severity Index (PDSI) (Table 1). The ESI algorithm (Fig. 1) uses the ALEXI model which was designed to minimize the need for *in situ* meteorological data.

$$ESI = 1 - f_{PET} = 1 - \frac{E}{PET} = 1 - \frac{E_C + E_S}{PET_C + PET_S}$$

Figure 1. *ESI equation from "A climatological study of evapotranspiration and moisture stress across the continental United States based on thermal remote sensing: 2. Surface moisture climatology" (Anderson et al. 2007b).*

Where f_{PET} is the ratio of actual evapotranspiration (ET) to potential evapotranspiration (PET). E_C, E_S and E are the modeled ET fluxes (mm) from the canopy, soil, and combined plant-soil system respectively, and PET_C, PET_S, and PET are potentials associated with these same variables. The above variables have a value of 0 when there is ample moisture/no stress, and a value of 1 when evapotranspiration has stopped due to stress and\or the soil is completely dry. (Anderson et al. 2007b).

Table 1. *Drought indicators for eight drought indices. Taken from "Evaluation of Drought Indices Based on Thermal Remote Sensing of Evapotranspiration over the Continental United States" (Anderson et al. 2011).*

Index	Acronym	Type
U.S. Drought Monitor	USDM	Multi-index synthesis
Evaporative stress index (X-month composite)	ESI-X	Remote sensing of f_{PET}
Evapotranspiration index (X-month composite)	ETI-X	Remote sensing of ET
Standardized precipitation index (X month)	SPI-X	Precipitation
Palmer *Z* index	*Z*	Precipitation + storage
Palmer drought severity index	PDSI	Precipitation + storage
Palmer modified drought index	PMDI	Precipitation + storage
Palmer hydrologic drought index	PHDI	Precipitation + storage

The spatial resolution of the ALEXI ESI is constrained by the resolution of GOES source data which is 5 km (Note: there is a technique, (DisALEXI) that uses thermal infrared (TIR) and vegetation index (VI) data from Landsat or MODIS to map vegetative stress at 60 m (Landsat thermal band) to 1 km (MODIS)).

The benefits of the ESI include the ability to see indications of vegetation stress before any deterioration of vegetation occurs. TIR-based indices such as ESI can provide an effective early warning of impending drought effects. The ESI can have much higher temporal resolution due to the use of the geostationary satellites. Furthermore, ESI can be used to predict "flash droughts", or events that occur rapidly and are driven by:

1. Precipitation deficits
2. High temperature anomalies
3. Strong winds
4. Anomalous incoming solar radiation

Some drawbacks of the ESI are: (1) it includes non-precipitation related moisture signals, like irrigation, vegetation rooted to groundwater. and lateral flows of groundwater, and (2) ESI is strongly affected by cloud cover. The latter can reduce the temporal resolution by making the acquired imagery data unusable. However, Choi et al. (2013) showed the performance of ESI was superior to the other drought indices under moderate drought conditions but was less effective in the case of severe droughts. (3) Using the current GOES satellites require merging data from 7 satellites, including resolving time differences, view angles, and atmospheric correction. It is possible to use a technique to train a regression model to use day-night LST differences from MODIS to predict the morning LST rise needed by the ALEXI model. This approach has the drawback though that polar orbiting sensors like MODIS and VIIRS only pass two times per day.

Literature Cited:

Anderson, M. C., J. M. Norman, J. R. Mecikalski, J. A. Otkin, and W. P. Kustas. 2007a. A climatological study of evapotranspiration and moisture stress across the continental United States based on thermal remote sensing: 1. Model formulation. Journal of Geophysical Research. Vol. 112, No. D10117, pp 1-17. URL = https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2006JD007506

Anderson, M. C., J. M. Norman, J. R. Mecikalski, J. A. Otkin, and W. P. Kustas. 2007b. A climatological study of evapotranspiration and moisture stress across the continental United States based on thermal remote sensing: 2. Surface moisture climatology. Journal of Geophysical Research. Vol. 112, No. D11112, pp. 1-13. URL = https://www.researchgate.net/publication/257881466_Climatological_study_of_evapotranspiration_and_moisture_stress_across_the_continental_United_States_based_on_thermal_remote_sensing_2_Surface_moisture_climatology

Anderson, M. C., C. Hain, B. Wardlow, A. Pimstein, J. R. Mecikalski, and W. P. Kustas. 2011. Evaluation of Drought Indices Based on Thermal Remote Sensing of Evapotranspiration over the Continental United States. Journal of Climate. Vol. 24, 15 April 2011, pp 2025-2044. URL = https://journals.ametsoc.org/view/journals/clim/24/8/2010jcli3812.1.xml

Anderson, M. C., C. A. Zolin, C. R. Hain, K. Semmens, M. T. Yilmaz, and F. Gao. 2015. Comparison of satellite-derived LAI and precipitation anomalies over Brazil with a thermal infrared-based Evaporative Stress Index for 2003-2013. Journal of Hydrology. Vol. 526, pp. 287-302. URL = http://dx.doi.org/10.1016/j.jhydrol.2015.01.005

Choi, M., J. M. Jacobs, M. C. Anderson, and D. D. Bosch. 2013. Evaluation of drought indices via remotely sensed data with hydrological variables. Journal of Hydrology. Vol. 476, January 2013, pp. 265-273. URL = https://www.sciencedirect.com/science/article/pii/S0022169412009420