Understanding vegetation moisture and rainfall relationship leading towards integrated drought index from Remote Sensing

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12th November, 2014
Introduction

• Periods of persistent abnormally dry weather, known as droughts, can produce a serious agricultural, ecological, or hydrological imbalance.

• Remote sensing based methods provides efficient means to measure soil and vegetation moisture conditions for drought characterization and operational system over large areas continuously across the space and time.
**Introduction**

Remote Sensing based drought indices

- **Spectral properties of soil**
- **Thermal Inertia**
- **Vegetation Indices (VI)**
  - Land Surface Temperature (LST)
  - VI and LST
  - VI, LST, and Rainfall (TRMM)

<table>
<thead>
<tr>
<th>Drought Indices</th>
<th>Formula</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized Multiband Drought Index (NMDI)</td>
<td>(R_2 - (R_6 - R_7))/(R_2 - (R_6 + R_7))</td>
<td>Wang and Qu, 2009</td>
</tr>
<tr>
<td>Thermal Inertia</td>
<td>(λC_T)^{1/2}</td>
<td>Watson et al., 1971</td>
</tr>
<tr>
<td>Apparent Thermal Inertia (ATI)</td>
<td>(1 - α) ΔT</td>
<td>Verstraeten et al., 2006</td>
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<tr>
<td>Normalized Difference Vegetation Index (NDVI)</td>
<td>(NIR - R)/(NIR + R)</td>
<td>Tucker, 1979</td>
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<td>Anomaly of Normalized Difference Vegetation Index (NDVIA)</td>
<td>NDVIμ - NDVI</td>
<td>Anyamba et al., 2001</td>
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<tr>
<td>Standardized Vegetation Index (SVI)</td>
<td>NDVI - NDVIμ / NDVIσ</td>
<td>Peters et al., 2002</td>
</tr>
<tr>
<td>Vegetation Condition Index (VCI)</td>
<td>(NDVI - NDVImin) / (NDVImax - NDVImin)</td>
<td>Kogan, 2002</td>
</tr>
<tr>
<td>Thermal Condition Index (TCI)</td>
<td>(BTmax - BT) / (BTmax - BTmin)</td>
<td>Kogan, 2002</td>
</tr>
<tr>
<td>Vegetation Health Index (VHI)</td>
<td>0.5 (VCI) + 0.5 (TCI)</td>
<td>Kogan et al., 2004</td>
</tr>
<tr>
<td>Vegetation Supply Water Index (VSWI)</td>
<td>NDVI / LST</td>
<td>Carlson et al., 1994</td>
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<tr>
<td>Drought Severity Index (DSI)</td>
<td>ΔLST - ΔNDVI</td>
<td>Bayarjargal et al., 2000</td>
</tr>
<tr>
<td>Temperature - Vegetation Drought Index (TVDI)</td>
<td>(LST – LSTmin)/(a+b.NDVI – LST min)</td>
<td>Sandholt et al., 2002</td>
</tr>
<tr>
<td>Crop Water Stress Index (CWSI)</td>
<td>(LSTmax - LST) / (LSTmax - LSTmin)</td>
<td>Moran, 2004</td>
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</tbody>
</table>
Objectives of the study

Developing remote sensing based moisture deviation index on vegetative surface to estimate water stress conditions

The main objective of this study is to develop an integrated drought index based on the NDVI, LST and TRMM data sets.

- Computing vegetation moisture index-Normalized Vegetation Water Supply Index (NVSWI), and Precipitation Condition Index (PCI)
- Analysis of co-variance of PCI time series and NVSWI time series. More specifically, identify if there is lag – time correlation among the two time series.
- Analysis of co-variance of the two time series corresponding to major LCLU classes in the area
- A way forward to integration of the two time series for developing integrated drought index

*TRMM: Tropical Rainfall Measurement Mission*
**Study area**

Total area ~ 14 thousand km$^2$
### Materials and Methods – Data Used

<table>
<thead>
<tr>
<th>No.</th>
<th>Data / Product</th>
<th>Data Type</th>
<th>Time Range</th>
<th>Spatial Resolution</th>
<th>Temporal Resolution</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NDVI and QA / MOD13Q1</td>
<td>Raster</td>
<td>2008 - 2012</td>
<td>250 m</td>
<td>16 Days</td>
<td>Drought Index</td>
</tr>
<tr>
<td>2</td>
<td>Land Surface Temperature: MOD11A2</td>
<td>Raster</td>
<td>2008-2012</td>
<td>1 km</td>
<td>8 Day</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Rainfall: TRMM rainfall Data - 3B42</td>
<td>Raster</td>
<td>2008-2012</td>
<td>0.25°</td>
<td>Daily</td>
<td>Co-variance</td>
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<tr>
<td>4</td>
<td>In-situ Rainfall Data</td>
<td>Text</td>
<td>2008-2011</td>
<td></td>
<td>Monthly</td>
<td>Validation / Analysis</td>
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<tr>
<td>5</td>
<td>MODIS Land Cover / MCD13Q1 (2009)</td>
<td>Raster</td>
<td>NA</td>
<td>500 m</td>
<td></td>
<td>Analysis</td>
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<tr>
<td>6</td>
<td>Global Land Cover (2000)</td>
<td>Raster</td>
<td>NA</td>
<td>30 m</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Administrative Boundaries of China</td>
<td>Vector</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NDVI: Normalized Difference Vegetation Index  
QA: Quality Assessment  
TRMM: Tropical Rainfall Measurement Mission
Materials and Methods – Drought Index

Vegetation Supply Water Index (VSWI) is ratio of NDVI to LST (Carlson et al., 1990).

\[
VSWI = \frac{NDVI}{LST}
\]

\[
NVSWI = \frac{VSWI - VSWI_{min}}{(VSWI_{max} - VSWI_{min})} \times 100
\]

- NVSWI: Normalized VSWI; \( VSWI_{min} \) and \( VSWI_{max} \): are temporal minimum and maximum value of VSWI
- NVSWI ranges from 0 (Driest) to 100 (Wet).
- Five drought classes, Severe Dry (< 20), Moderate drought (20 – 40), Slight drought (40-60), Normal (60 – 80), and Wet (> 80).

(Sandholt et al., 2002)
**Materials and Methods – Rainfall Anomaly**

Standardized difference of monthly rainfall (2008-2011) from the mean rainfall of the period (1961–2007)

\[
    PDI = \frac{(R - R_m)}{(R_{max} - R_{min})} \times 100
\]

Where, R is rainfall of corresponding month, \( R_m \) is the historic average of rainfall of the month, \( R_{min} \) and \( R_{max} \), are minimum and maximum rainfall of month during the period.

*Anomaly: deviation or departure from the normal or common order*
Monthly rainfall measures of TRMM and in-situ rainfall measures were compared over the period. And regression analysis was performed on 60 observations pertaining in the period.

The rainfall estimation is spatio-temporal climate component but it cannot be directly analysed with NVSWI. Therefore, PCI, which is normalized rainfall for the detection of the precipitation deficits from climate signal, was also computed

\[ PCI = \frac{(TRMM - TRMM_{min})}{(TRMM_{range})} \times 100 \]

where TRMM, TRMM\(_{min}\) and TRMM\(_{range}\) corresponds to rainfall, minimum rainfall over the period, and range of the rainfall values, respectively. PCI ranges from 0 – 100 corresponding to changes in precipitation from extremely unfavourable to optimal. In case of a meteorological drought which has an extremely low precipitation, the PCI is close or equal to 0, and at flooding conditions, the PCI is close to 100.
Materials and Methods – Covariance of PCI and NVSWI

The responses between NVSWI and PCI time series to rainfall series with different lag-time scales (0, 16, 32 ... 128 days) was analysed using Pearson’s Cross Correlation (PCC) coefficients analysis

\[
PCC = \frac{\sum_{t=0}^{L-1} [(T_{t}^{a} - \overline{T_{t}^{a}}) \times (T_{t-\text{lag}}^{b} - \overline{T_{t-\text{lag}}^{b}})]}{\left( \sum_{t=0}^{L-1} [(T_{t}^{a} - \overline{T_{t}^{a}})]^2 \right)^{0.5} \times \left( \sum_{t=0}^{L-1} [(T_{t-\text{lag}}^{b} - \overline{T_{t-\text{lag}}^{b}})]^2 \right)^{0.5}}
\]

where \( T_{t}^{a} \) and \( T_{t}^{b} \) corresponds to NVSWI and PCI time series, respectively; \( L \) is the length of time series, lag is the length of temporal shift applied before the correlation, and \( t \) refers to the single time step of the time series [34]. This analysis was performed up to 9th lag period corresponding to 0, 16, 32, ..., 128 days lag-periods.
Based on cross correlation between NVSWI and PCI, we propose Accumulated Precipitation Condition Index (APCI) that is a modified form of PCI.

\[
APCI = \frac{1}{n} \sum_{i=0}^{n} R_i \times PCI_i
\]

Where, \( n \) is equal to number of lag periods, \( R \) corresponds to normalized (0 to 1) correlation coefficient value between PCI and NVSWI corresponding to lag period \( i = 0, 1, 2, \ldots n \).
Materials and Methods – Integration of PCI and NVSWI

In the last step towards integrating drought development of integrated drought index, APCI and NVSWI time-series were combined using weighted sum of the two time-series to produce Integrated Vegetation Moisture Index (IVMI)

\[ IVMI = A_1 \times NVSWI + A_2 \times APCI \]

Where, \( A_1 \) and \( A_2 \) are corresponding weights for NVSWI and APCI, respectively. Since NVSWI provide more spatial details and compared to APCI, therefore it is suggested to give higher weight to NVSWI as compared to APCI, therefore here we used \( A_1 = 0.6, A_2 = 0.4 \).
Results and Discussion – Spatio-temporal patterns of drought

Year to year spatial patterns of moisture conditions

Results and Discussion – Validation of TRMM rainfall

Regression analysis between TRMM and in-situ rainfall measurements

Comparison of TRMM and in-situ rainfall measurements

Time series plots of Calibrated TRMM (by 2 * SD) and Met Station Rainfall
Results and Discussion – PCI and NVSWI time series

Time series plot of NVSWI and PCI (averaged across the space)

Cross Correlation coefficient between NVSWI and PCI (averaged across the space)

SPI and NVSWI time series plots.
Results and Discussion- NVSWI, PCI and APCI

Correlation between spatially averaged NVSWI of the LCLU classes and PCI time series with different lag times.
Results and Discussion – APCI and IVMI

The NVSWI for each cover type with the lag removed by the APCI computation.

Time series plots of IVMI for the each of major LCLU class
• Integration of satellite based vegetation index (NDVI), land surface temperature (LST) and rainfall (TRMM) data at an interval of every 16 days can provide effective operational means to monitor drought conditions over large areas.

• The NVSWI is found to be effective to monitor droughts in dense vegetation covered areas.

• Cropland and Shrub exhibited highest correlation with 4th lag period (i.e., 64 days earlier rainfall) whereas Evergreen Forest exhibited highest correlation 5th lag period (i.e., 80 days earlier rainfall).

• Monitoring of preseason rainfall is significantly important to track the development of drought conditions.

• Time lag can between rainfall and moisture condition can be removed prior to integration of the measurements.
Thank you for your attention
Recommendation

• Integration of rainfall with LST and NDVI; weighted sum of rainfall according to strength of correlation with the lag time.

• Long term analysis to probe the winter rainfall event with maximum affect on vegetation production in upcoming spring season.

• Extraction of drought-phenology (on-set of drought, length of drought, End of drought) and drought severity (minimum value of drought index, time of minimum value), and then analyze the relation with climate variables over longer time.

• Analyze the drought characteristic (severity, length and areal extent) for Tree Crops and Field Crops, and different natural vegetation (Shrubs, Grasses, and Forest Types).
**Materials and Methods - Preprocessing**

**NDVI MODIS (MOD13Q1):**
- Selection of minimum viewing zenithal angles
- Selection of NDVI maximum values
- Masking of residual clouds with QA bands

### Relationships of indices for various noises:
- **CLOUD and FOG** - red↑, NIR↑, NDVI↓
- **SNOW and ICE** - red↑, NIR↑, NDVI↓

### Bit No. Binary Code Description

<table>
<thead>
<tr>
<th>Bit No.</th>
<th>Binary Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-15</td>
<td>00</td>
<td>VI produced, good quality</td>
</tr>
<tr>
<td>14-15</td>
<td>01</td>
<td>VI produced, but check other QA</td>
</tr>
<tr>
<td>14-15</td>
<td>10</td>
<td>Pixel produced, but most probably cloudy</td>
</tr>
<tr>
<td>14-15</td>
<td>11</td>
<td>Pixel not produced due to other reasons than clouds</td>
</tr>
</tbody>
</table>

### Cleaning NDVI Time-Series

**Double Logistic Function used for the Study:**

\[
NDVIt = NDVI_{min} + NDVI_{d} \left( \frac{1}{1+e^{-Lm(t-L)}} + \frac{1}{1+e^{-Rm(t-R)}} - 1 \right)
\]

- \(NDVIt\) = NDVI of the pixel at day of the year (DOY)
- \(NDVI_{min}\) = Minimum NDVI of NDVI trajectory during the year (lower asymptote)
- \(NDVI_{d}\) = Difference of minimum and maximum (lower and upper asymptote) of NDVI trajectory during the year
- \(L\) = Position of left inflection point (change of concavity), point (DOY) where the slope of the function has maximum change (Maximum rate of increase in NDVI), in spring, nominal start of the season
- \(R\) = Position of right inflection point (change of concavity), point (DOY) where the slope of the function has maximum change (Maximum rate of decrease in NDVI), in autumn.
- \(Lm\) = Maximum Slope of the curve at left inflection point, Maximum rate of increases in NDVI
- \(Rm\) = Maximum Slope of the curve at right inflection point, Maximum rate of decreases in NDVI

*(Bussetto et al., 2010; Butt et al., 2011)*
MODIS LST (MOD11A2):

• in total 330 images were processed
• 8 day product, comprises 2 to 8 day average of best quality pixels with clear-sky conditions (Zhou et al., 2012).

• Merged two consecutive 8-day LST products for a 16-day composite

TRMM daily global product (3B42):

• Extent: 50° N to 50° S; spatial resolution: 0.25
• in total 1825 images were processed
• Daily rainfall accumulated over 16- Day interval to match with the composite resolution of LST and NDVI products
Materials and Methods – Land Cover Land Use Map

• Land Cover Land Use (LCLU) map of the study was prepared from two available global LCLU products, MODIS product and GLC2000.

• GLC2000 was based on 30 m Landsat images and was better than MODIS land cover, however, urban areas were better mapped in MODIS product.

• ‘Grassland’ class in GLC2000 was actually identified as Cropland and hence it was merged with ‘Cropland’

• 7 LCLU classes, viz., Built-up Area, Cropland (CL), Shrub (SB), Deciduous Forest (DF), Evergreen Forest (EF), Mixed Forest (MF), and Water (W)
Description of the study area

Hot spot for meteorological and drought studies due history of frequent droughts.

Average annual air temperature increased about 0.8 °C (Liu et al., 2010)

Average annual precipitation decreased about 50 mm (Liu et al., 2010)

(Huang et al. 2011)

(Li et al. 2011)

• *Diagnosis of the Severe Drought in Autumn/Winter 2009-2010 in Yunnan Province. TROPICAL GEOGRAPHY.31*(1):28-33.)