Vegetation Outlook for the Greater Horn of Africa (VegOut-GHA): A Seasonal Prediction Model

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Satellite-based Vegetation Monitoring Approach

Satellite-based remote sensing has been widely used over the past 30+ years for national to global-scale many environmental monitoring activities, including drought monitoring.

Satellite-based VIs have proven to function as indicators of various biophysical characteristics of vegetation such as:
- percent of green cover
- green biomass
- fraction of absorbed photosynthetically-active radiation (fAPAR)
- chlorophyll content
- leaf area index

One of the Vis widely used is the NDVI

Visible red radiation is strongly absorbed by plant pigments (chlorophyll)
NIR radiation is strongly reflected by the internal cell structure of leaves (spongy mesophyll layer)

High contrast for healthy, green photosynthetically-active vegetation that increases with the amount of green vegetation resulting in higher (or increasing) NDVI values.

Lower contrast as the amount of green photosynthetically-active plant material declines resulting in lower (or decreasing) NDVI values.
The Vegetation Monitoring Approach

Normalized Difference Vegetation Index (NDVI) data (and NDVI derivatives) from satellite have been used for 30+ years for this agricultural drought monitoring applications throughout the world.

- Readily available spectral data for index calculation (AVHRR) – sensor degraded since Nov 2016.
- MODIS NDVI is currently used (data: 2001–present)
- Simple mathematical calculation

\[
\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}
\]

- Strong relationship with various biophysical characteristics of vegetation

Geographic patterns of seasonal vegetation greenness as observed from a time-series derived from the NOAA/NESDIS second generation global vegetation index (GVI2) dataset.
Challenges for Drought Monitoring:
1. Discrimination of drought-impacted areas from locations experiencing other types of stress (pests, plant disease, flooding, and fire) or land use/land cover change (i.e., the need for integrating the remote sensing data with climate and other biophysical data)
2. Classification of different drought severity levels (e.g., moderate, severe, and extreme).
3. Prediction of the vegetation condition (several approaches including time-lag relationships)
4. Evaluation of monitoring and predicted products is also challenging (mainly due to lack of ground observations).
Introduction:
What is VegOut?

- **An experimental tool** to provide future outlooks of general vegetation conditions (seasonal greenness) based on an analysis of information that integrates climate, satellite, biophysical, and oceanic data.

- **Experimental Model for central U.S.**
  - Series of maps depicting future outlooks of general vegetation conditions at a 1-km² spatial resolution that are updated every 2 weeks (AVHRR-based) or every week (MODIS-based) models.
    1) 2-week Vegetation Outlook map
    2) 4-week Vegetation Outlook map
    3) 6-week Vegetation Outlook map
VegOut Methodology

1. Historical Database Development

Satellite

- Data Input Variables
  1. Standardized Seasonal Greenness (SSG)
  2. Start of Season Anomaly (SOSA)

Climate Data

- Standardized Precipitation Index (SPI)

Oceanic Data

- Atlantic Multi-decadal Oscillation Index (AMO)
- Multivariate ENSO Index (MEI)
- Madden-Julian Oscillation
- Pacific North American index (PNA)
- Pacific Decadal Oscillation (PDO)
- Southern Oscillation Index (SOI)
- North Atlantic Oscillation (NAO)

Biophysical Data

- Land use/cover type
- Soil available water capacity (STATSGO)
- Ecoregion type
- Irrigation status
- Elevation

2. Model Development

Regression Tree Model*

3. Map Generation

- 2-week outlook
- 4-week outlook
- 6-week outlook

VegOut Maps

(* Model developed from an 18-year historical record (1988–2006) of bi-weekly climate and satellite observations at 1,402 weather station locations.

Oceanic data are extracted for the same period of time.

Biophysical variables are static over time.

Figure. VegOut database, process (regression-tree rules generation), and outlook map production.

(Tadesse et al., 2010, GIScience & Remote Sensing)
Time-series relationship model
(Climate-vegetation time-lag relationship based on historical pattern)

Model

Method: Given the current independent climate, satellite, and biophysical variables at the current condition, what would be the value in the following week or 10-day to 4 months period based on the historical pattern?

- **The VegOut modeling approach:**

Example:

\[
\text{VegOut}_{t-i(1 \text{ month})} = f_{t=0}(\text{SSG/MODIS}) + f_{t=0}(\text{Precip/CHIRPS, Noah_SM, LULC, Eco}_R, \text{DEM}) + f_{t=priorMonth}(\text{MEI, NAO, PDO, SOI, AMO, SSTA, PNA})
\]
## Evaluation of the VegOut model

<table>
<thead>
<tr>
<th>Period</th>
<th>Outlooks</th>
<th>Evaluation on test data</th>
<th>Period</th>
<th>Outlooks</th>
<th>Evaluation on test data</th>
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<td></td>
<td></td>
<td>MAD (T)</td>
<td>RE (T)</td>
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<td>4-week</td>
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<td>0.37</td>
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<tr>
<td>Period 13 (18 Jun - 1 July)</td>
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<td></td>
<td></td>
<td>4-week</td>
<td>0.17</td>
<td>0.24</td>
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<td>6-week</td>
<td>0.22</td>
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<td>Period 14 (2 - 15 July)</td>
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<td>0.16</td>
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<td>0.18</td>
<td>0.96</td>
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<tr>
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<td>6-week</td>
<td>0.17</td>
<td>0.24</td>
<td>0.92</td>
</tr>
<tr>
<td>Period 17 (13 - 26 August)</td>
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<td>0.96</td>
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<td>6-week</td>
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<tr>
<td>Period 18 (26 Aug – 9 Sept)</td>
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<td>4-week</td>
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<td>0.98</td>
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<td>6-week</td>
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<td>N/A</td>
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Table 2. Evaluation of the VegOut model. The mean absolute difference (MAD) values, relative error (RE), and coefficient of determination (R²) between the observed and predicted SSG are shown for each period and the corresponding outlooks in all periods of the growing season. (Tadesse et al., 2010, GIScience & Remote Sensing)
Figure 4. (a) Observed seasonal greenness (SSG) for July 28, 2008; (b), (c), and (d) are 2-, 4-, and 6-week outlooks; (e), (f), and (g) are observed SSG for August 11, August 25, and September 8 that correspond to the 2-, 4-, 6-week outlooks, respectively; (h), (i), and (j) are the change maps (the difference between the predicted and observed) for the 2-, 4-, 6-week outlooks, respectively. (After Tadesse et al., 2010, GIScience & Remote Sensing)
NASA GHA: VegOut-GHA Database Development

<table>
<thead>
<tr>
<th>No.</th>
<th>Input parameters</th>
<th>Resolutions</th>
<th>Data years</th>
<th>Updated year</th>
<th>Source</th>
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<td>2015</td>
<td>USGS famine early warning systems network (FEWS NET)</td>
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<td>3</td>
<td>Digital Elevation Model (DEM)</td>
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<td>USGS</td>
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<td>4</td>
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<td>Dekadal: 5Km, Spatial: 5Km</td>
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<td>2015</td>
<td>Climate Hazards Group Infrared Precipitation with Stations (CHIRPS)</td>
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<td>5</td>
<td>Ecoregion</td>
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<td>The Nature Conservancy</td>
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<td>Evaporation Stress Index (ESI)</td>
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<td>2015</td>
<td>USDA/NOAA</td>
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<td>7</td>
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<td>2014</td>
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<td>European Soil Portal - Soil Data and Information Systems</td>
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</table>

List of Oceanic/atmospheric indices considered

- Atlantic Meridional Mode (AMM)
- Atlantic Multi-decadal Oscillation (AMO)
- Bivariate ENSO Time Series (BEST)
- Dipole Mode Index (DMI)
- Multivariate ENSO Index (MEI)
- North Atlantic Oscillation (NAO)
- East Central Tropical Pacific SST (NINO3.4) Index
- Central Tropical Pacific SST (NINO4) Index
- Oceanic Niño Index ONI
- Pacific Decadal Oscillation (PDO)
- Pacific-North American (PNA)
- Quasi-Biennial Oscillation (QBO)
- Solar Flux Index (SFI)
- Southern Oscillation Index (SOI)
- Tropical North Atlantic Index (TNA)
- Trans-Nino Index (TNI)
- Tropical South Atlantic Index (TSA)

Oceanic/Atmospheric Indices

<table>
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<tr>
<th>No.</th>
<th>Selected Index</th>
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<td>1</td>
<td>Atlantic Meridional Mode (AMM)</td>
</tr>
<tr>
<td>2</td>
<td>Dipole Mode Index (DMI)</td>
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<td>3</td>
<td>Multivariate ENSO Index (MEI)</td>
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<td>4</td>
<td>Oceanic Niño Index (ONI)</td>
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<tr>
<td>5</td>
<td>Pacific Decadal Oscillation (PDO)</td>
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<tr>
<td>6</td>
<td>Tropical North Atlantic Index (TNA)</td>
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<tr>
<td>7</td>
<td>Trans-Nino Index (TNI)</td>
</tr>
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</table>
**VegOut-GHA Model Methodology**

### Input Data
- MODIS-based Normalized Difference Vegetation Index (NDVI)
- Standardized Seasonal Greenness (SSG)
- CHIRPS Standardized Precipitation, Z-score (dekadal)
- Soil Water Holding Capacity
- Ecoregions (Omernik Level III)
- Land Cover (European Space Agency)
- Digital Elevation (USGS)

### Satellite and Climate

### Biophysical

### Oceanic/Atmospheric

#### Step 1
Training Data
Historical database developed from satellite, biophysical, Oceanic, and climate data extracted for each grid locations

#### Step 2
Model Development
Regression-tree analysis to develop dekadal VegOut-GHA Models based on time-lag relationships

#### Step 3
Hindsight or Near-Real Time Data
Gridded image generation of hindsight or near-real time data inputs

#### Step 4
VegOut Maps Generation
Application of dekadal model to near-real time gridded inputs for Seasonal VegOut-GHA map generation

#### Step 5
VegOut-GHA Maps
Value-added Products & comparison

#### Step 6
Web-delivery
Internet Portal for data access and distribution
VegOut-GHA Model Regression tree Rules:

Example:

Rule 1: [32059 cases, mean -0.05, range -3.18 to 2.97, est err 0.28]

if LCLU = Crop land
DEM > 2100
SSG_0 <= -0.5
then VegOut-GHA = -3 + 0.85 SSG_0 - 1.3 AMM - 0.2 MEI + 0.6 P_Z-Score + 0.3 SM

Rule 2: if ... then
.
.
.
Rule 30: if ... then

VegOut-GHA Model Evaluation on Test Data
May 21-31, 2015

June 1 - 10, 2015

June 21 - 30, 2015

July 21 - 31, 2015

August 21 - 31, 2015

Vegetation Condition
- Extreme Stress
- Severe Stress
- Moderate Stress
- Poor Vegetation
- Near Normal
- Fair Vegetation
- Good Vegetation
- Very Good Vegetation
- Excellent Vegetation
- Scarce Vegetation
- Dry Season
- Water
- Country Boundary

Difference Map
Predicted – Observed (+/- 1 STD)
- Over-predicted
- Similar
- Under-predicted

10-day outlooks

1-month outlook

2-month outlook

3-month outlook

Observed SSG

Observed SSG

Observed SSG

Observed SSG

$R^2 = 0.99$

$R^2 = 0.83$

$R^2 = 0.82$

$R^2 = 0.63$
## Spatial Pattern Correlation between the Observed and Model predicted SSG for the Greater Horn of Africa


### Evaluation model performance using retrospective forecast

<table>
<thead>
<tr>
<th>Year</th>
<th>Dekad</th>
<th>Coefficient of determination ($R^2$)</th>
<th>10-day Outlook</th>
<th>1-month Outlook</th>
<th>2-month Outlook</th>
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Validation – Work still in Progress

**USE OF CROP PRODUCTION DATA**

Comparing Zonal-Level Crop Yields to Drought Pattern of the VegOut-GHA

**Challenges:**
- Crop Yield estimation methods
- Data Quality - Incomplete or lack of historical observations

**Convergence of evidence’ approach** is needed where many types of information can be collectively analyzed to determine if the majority of information is ‘converging’ (telling the same story) about the accuracy or inaccuracy of the drought index being evaluated.

**EXAMPLE: ET ANOMALY VS CROP YIELD**
Final Thoughts

- The evaluation results (case studies on retrospective forecasts) show encouraging accuracy of predictability of the seasonal greenness
- Regional vs. Country based models (need collaboration with national institutes
  - comparisons
- Seasonality
  - Objective regionalization/ Climatically homogenous zones
- Evaluation should continue based on
  - Case studies
  - feedback from experts and users/potential users (e.g., farmers, ranchers, university extension agents, and managers)
- To improve the models, need to assess temporal and spatial relationships between
  - Climate & vegetation dynamics
  - Oceanic dynamics & climate
  - Teleconnection and Spatial variability of drought occurrences
    - Use these identified relationships to determine which variables to integrate in modeling the VegOut-GHA to improve prediction accuracy
Acknowledgements

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