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

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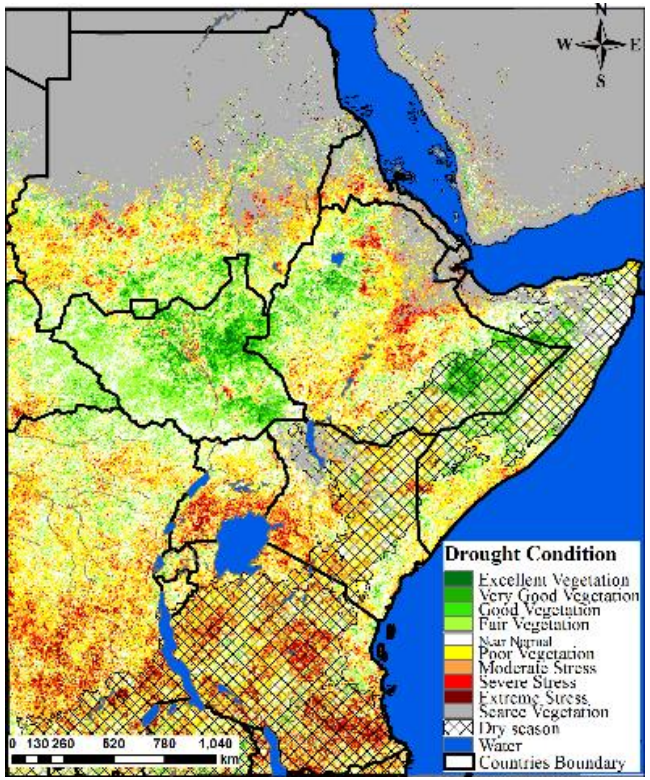

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The Third Participatory Research Workshop and Project Meeting 24-26 October 2017, Addis Ababa, Ethiopia

Remote Sensing for Drought/Vegetation Monitoring

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:

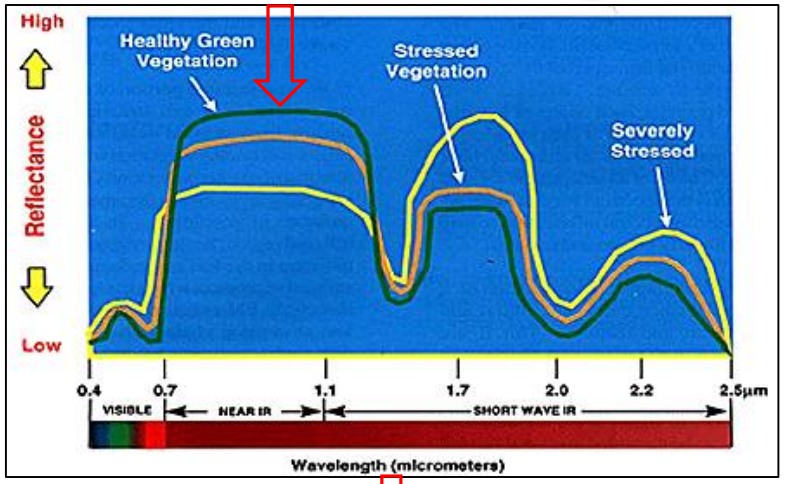
- percent of green cover
- green biomass
- fraction of absorbed photosynthetically-active radiation (fAPAR)
- chlorophyll content
- leaf area index

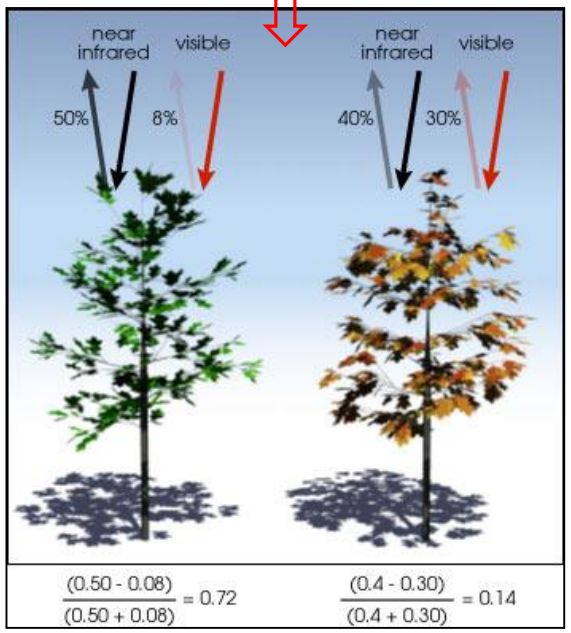
One of the Vis widely used is the NDVI

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

High contrast for healthy, green photosynthetic-actively 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.





Healthy Vegetation **Senesced or Stressed Vegetation**

Satellite Remote Sensing of Agricultural Drought

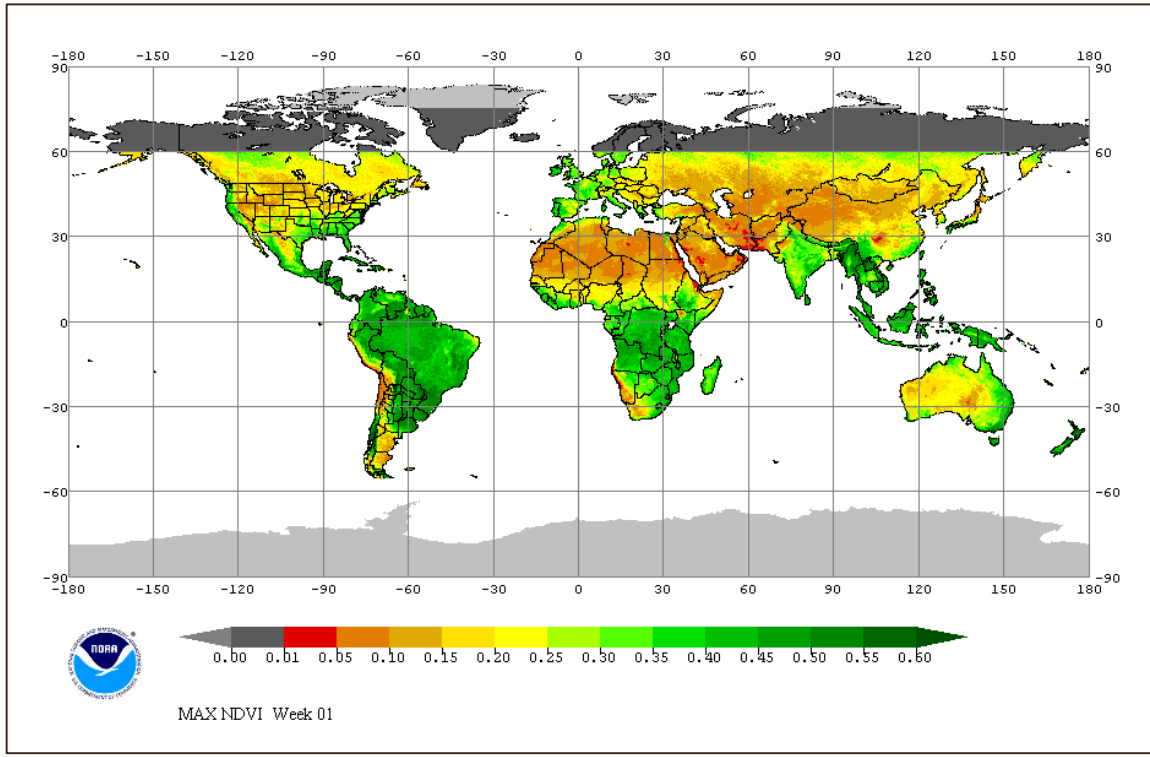
The Vegetation Monitoring Approach

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

$$\boxed{\mathbf{NDVI = (NIR - Red) / (NIR + Red)}}$$

- Strong relationship with various biophysical characteristics of vegetation

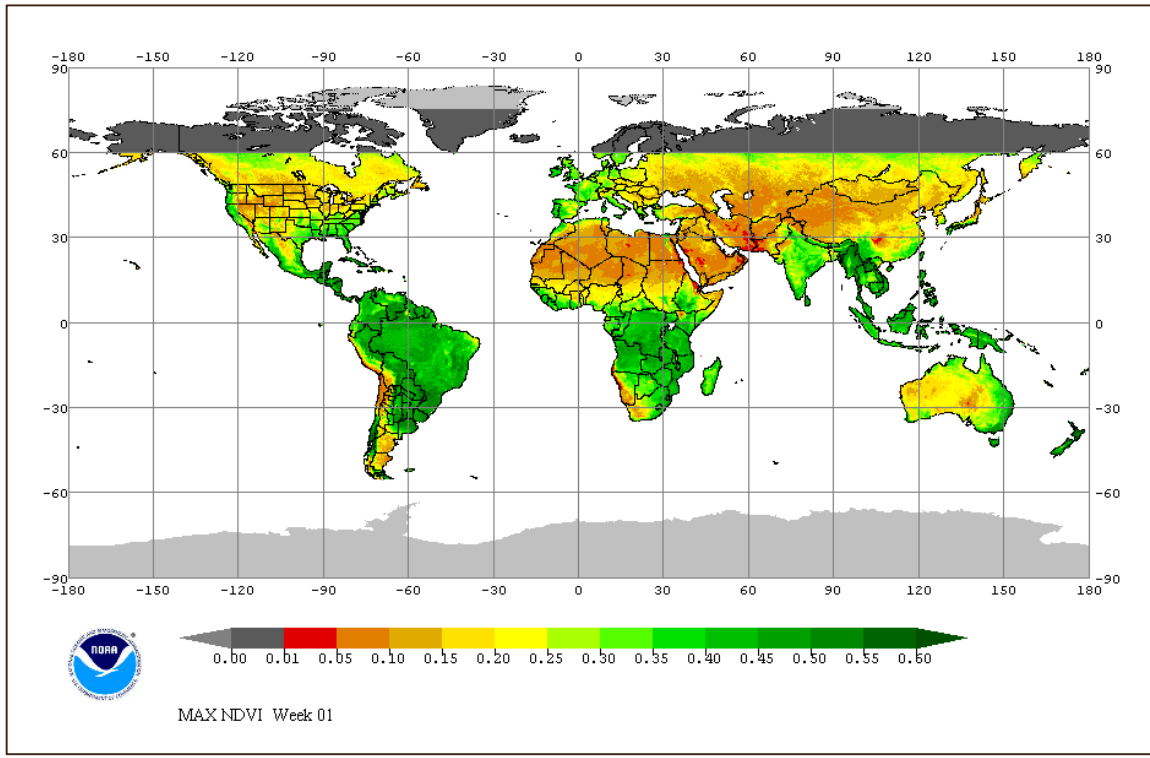


Geographic patterns of seasonal vegetation greenness as observed from a time-series derived from the NOAA/NESDIS second generation global vegetation index (GVI2) dataset.

Satellite Remote Sensing of Agricultural Drought

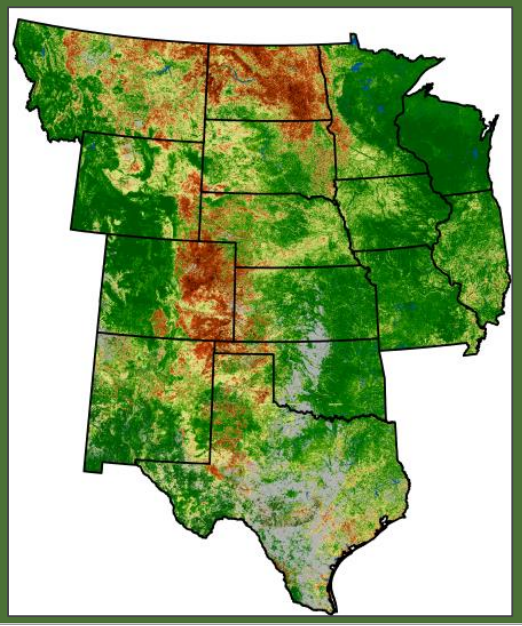
Challenges for Drought Monitoring:

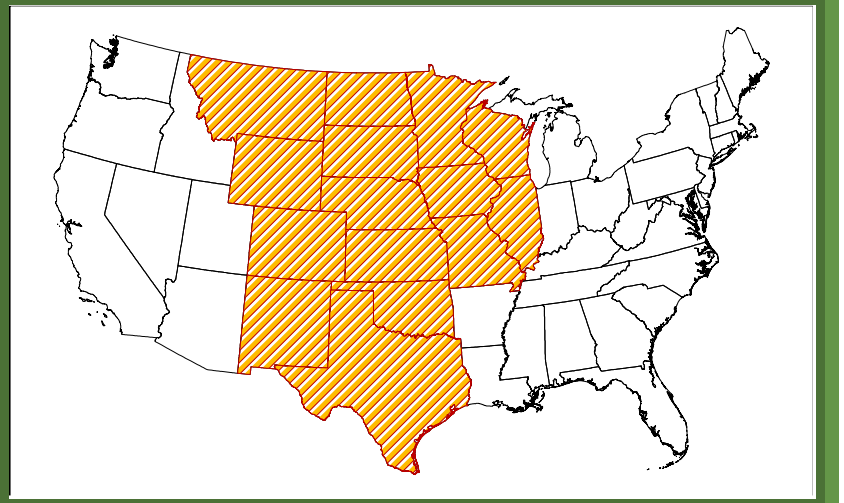
1. Discrimination of drought-impacted areas from locations experiencing other types of stress (pests, plant disease, flooding, and fire) or land use/land cover change (i.e., the need for integrating the remote sensing data with climate and other biophysical data)
2. Classification of different drought 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).



Geographic patterns of seasonal vegetation greenness as observed from a time-series derived from the NOAA/NESDIS second generation global vegetation index (GVI2) dataset.

Introduction: What is VegOut?

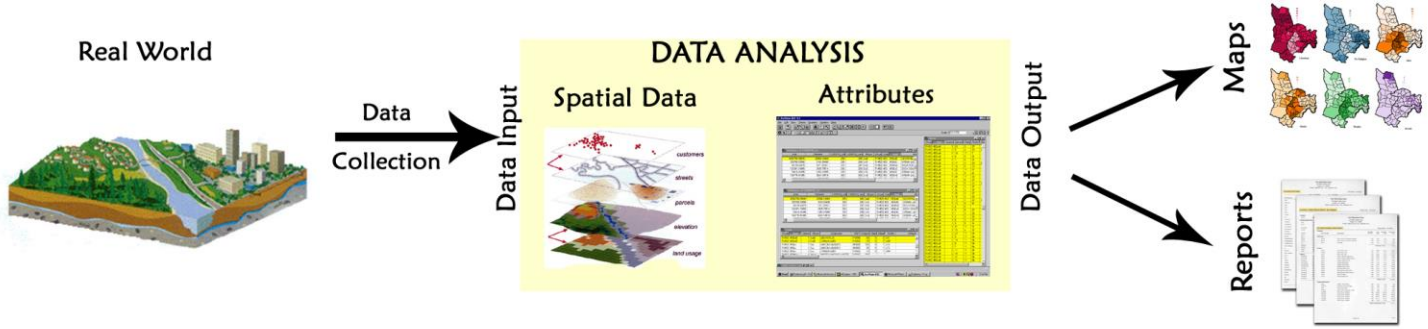




Vegetation Outlook (VegOut)

- **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-km^2 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

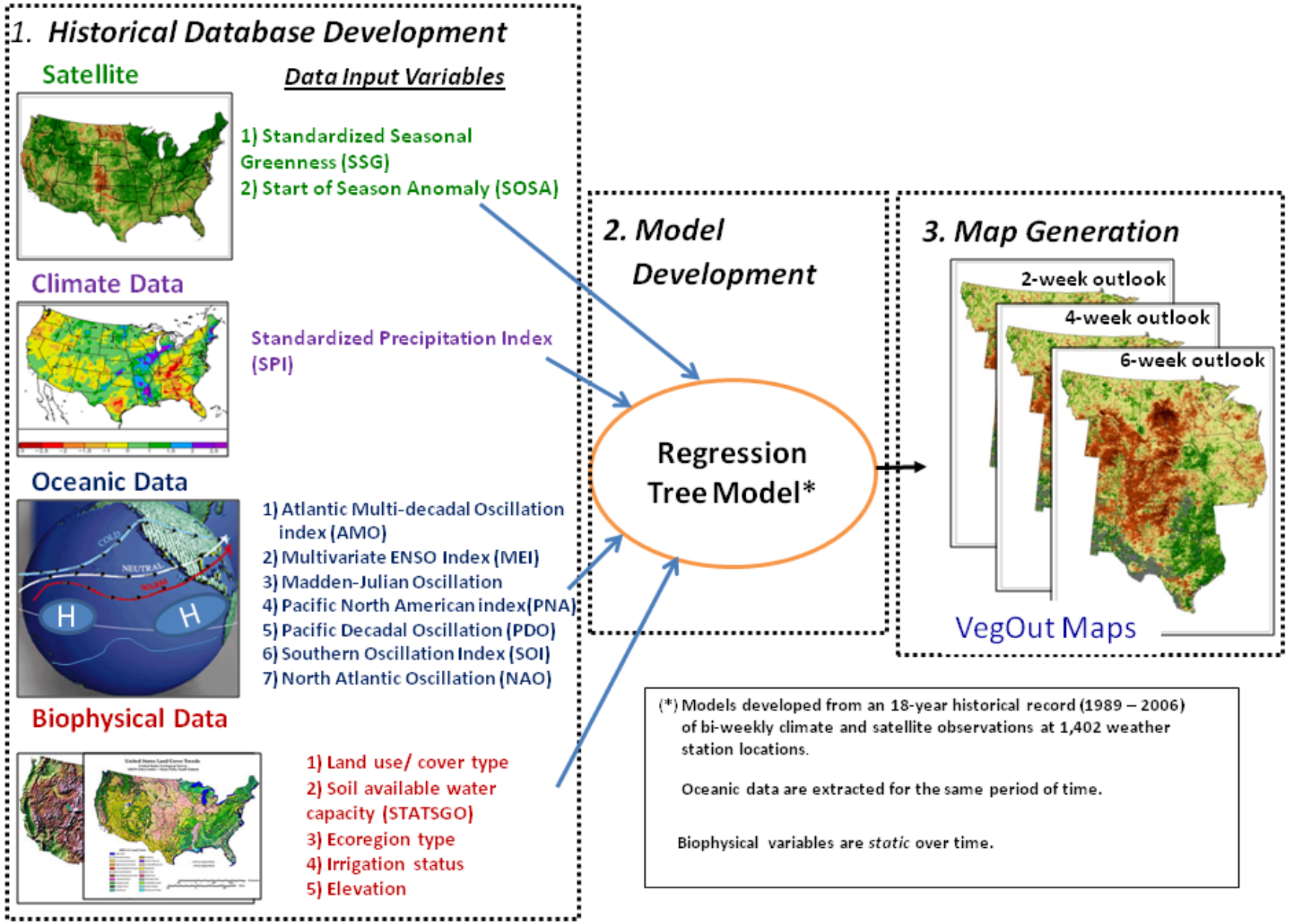


Figure. VegOut database, process (regression-tree rules generation), and outlook map production.

(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 or10-day to 4 months period based on the historical pattern?

- **The VegOut modeling approach:**

Example:

$$VegOut_{t=i(1\ month)} = f_{t=0}(SSG/MODIS) + f_{t=0}(Precip/CHIRPS, Noah_SM, LULC, Eco_R, DEM), + f_{t=priorMonth}\ (MEI, NAO, PDO, SOI, AMO, SSTA, PNA)$$

Evaluation of the VegOut model

Period	Outlooks	Evaluation on test data			Period	Outlooks	Evaluation on test data		
		MAD (T)	RE (T)	R^2			MAD (T)	RE (T)	R^2
Period 9 (23 April- 6 May)	2-week	0.25	0.37	0.83	Period 14 (2 – 15 July)	2-week	0.09	0.13	0.98
	4-week	0.33	0.49	0.72		4-week	0.16	0.23	0.92
	6-week	0.35	0.51	0.71		6-week	0.20	0.30	0.90
Period 10 (7 - 20 May)	2-week	0.17	0.25	0.92	Period 15 (16– 29 July)	2-week	0.09	0.12	0.98
	4-week	0.25	0.36	0.85		4-week	0.14	0.2	0.94
	6-week	0.31	0.45	0.77		6-week	0.18	0.26	0.92
Period 11 (21 May - 3 June)	2-week	0.14	0.21	0.94	Period 16 (30July-12 Aug)	2-week	0.08	0.11	0.98
	4-week	0.21	0.30	0.88		4-week	0.13	0.18	0.96
	6-week	0.28	0.41	0.81		6-week	0.17	0.24	0.92
Period 12 (4 - 17 June)	2-week	0.11	0.16	0.98	Period 17 (13–26 August)	2-week	0.07	0.10	0.98
	4-week	0.19	0.28	0.92		4-week	0.11	0.16	0.96
	6-week	0.26	0.37	0.85		6-week	0.15	0.21	0.94
Period 13 (18 Jun - 1 July)	2-week	0.10	0.14	0.98	Period 18 (26 Aug – 9 Sept)	2-week	0.06	0.09	0.99
	4-week	0.17	0.24	0.94		4-week	0.10	0.14	0.98
	6-week	0.22	0.32	0.88		6-week	N/A	N/A	N/A

Table 2. Evaluation of the VegOut model. The mean absolute difference (MAD) values, relative error (RE), and coefficient of determination (R^2) 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)

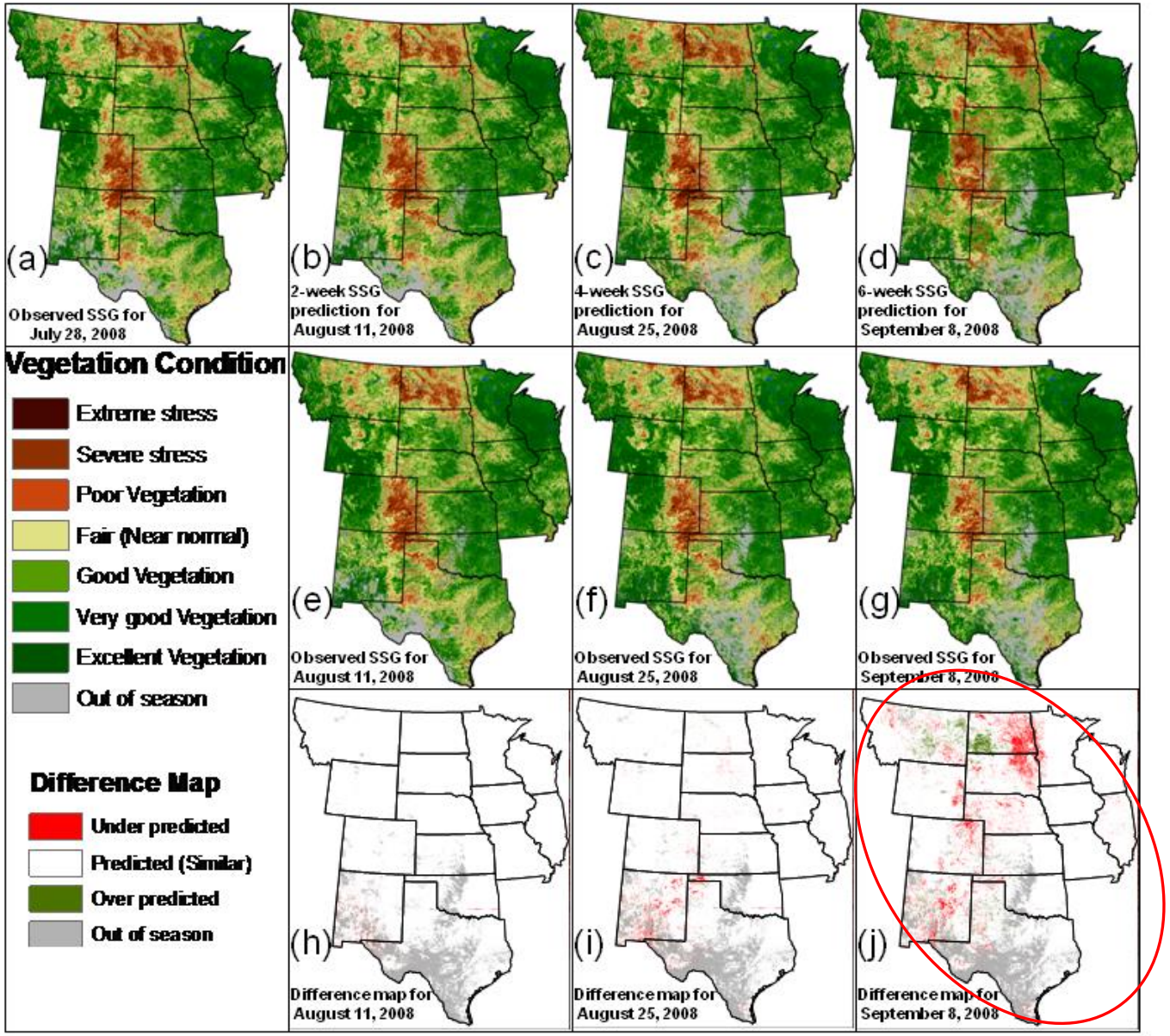


Figure 4. (a) Observed seasonal greenness (SSG) for July 28, 2008; (b), (c), and (d) are 2-, 4-, and 6-week outlooks; (e), (f), and (g) are observed SSG for August 11, August 25, and September 8 that correspond to the 2-, 4-, 6-week outlooks, respectively; (h), (i), and (j) are the change maps (the difference between the predicted and observed) for the 2-, 4-, 6-week outlooks, respectively. (After Tadesse et al., 2010, GIScience & Remote Sensing)

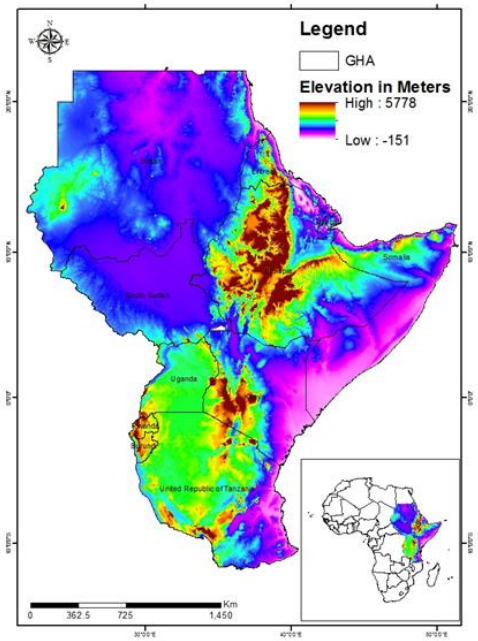
NASA GHA: VegOut-GHA Database Development

No.	Input parameters	Resolutions		Data years	Updated year	Source
		Temporal	Spatial			
1	Landcover		300 m		2008	European Space Agency (esa)
2	Normalized Difference Vegetation Index (NDVI)	Dekadal	250m	2001 - 2015	2015	USGS famine early warning systems network (FEWS NET)
3	Digital Elevation Model (DEM)		1 km		2010	USGS
4	Standard Precipitation Index (SPI)	Dekadal	5Km	1981 - 2013	2015	Climate Hazards Group Infrared Precipitation with Stations (CHIRPS)
5	Ecoregion				2008	The Nature Conservancy
6	Evaporation Stress Index (ESI)			2000-2013	2015	USDA/NOAA
7	Soil map and Available water content (AWC)		1:250000		2014	European Soil Portal - Soil Data and Information Systems

Oceanic/Atmospheric Indices

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)

No.	Selected Index
1	Atlantic Meridional Mode (AMM)
2	Dipole Mode Index (DMI)
3	Multivariate ENSO Index (MEI)
4	Oceanic Niño Index (ONI)
5	Pacific Decadal Oscillation (PDO)
6	Tropical North Atlantic Index (TNA)
7	Trans-Nino Index (TNI)



VegOut-GHA Model Methodology

Input Data

Satellite and Climate

- MODIS-based Normalized Difference Vegetation Index (NDVI)
- Standardized Seasonal Greenness (SSG)

CHIRPS Standardized Precipitation, Z-score (dekadal)

Biophysical

- Soil Water Holding Capacity
- Ecoregions (Omernik Level III)
- Land Cover (European Space Agency)
- Digital Elevation (USGS)

Oceanic/Atmospheric

- Atlantic Meridional Mode (AMM)
- Dipole Mode Index (DMI)
- Multivariate ENSO Index (MEI)
- Oceanic Niño Index (ONI)
- Pacific Decadal Oscillation (PDO)
- Tropical North Atlantic Index (TNA)
- Trans-Nino Index (TNI)

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

Step3

Hindsight or Near-Real Time Data

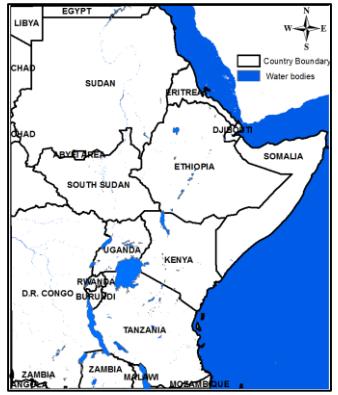
Gridded image generation of hindsight or near-real time data inputs

Step 4

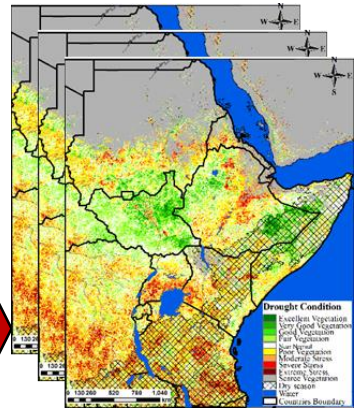
VegOut Maps Generation

Application of dekadal model to near-real time gridded inputs for Seasonal VegOut-GHA map generation

Step 5

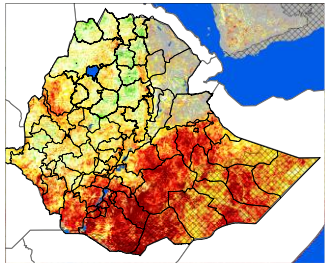


VegOut-GHA Maps

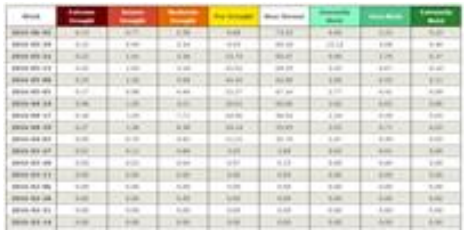


Value-added Products & comparison

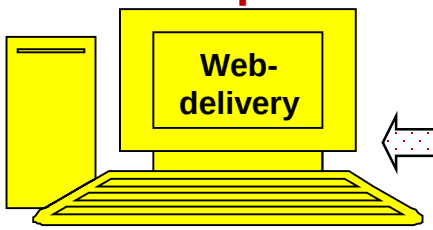
Country Maps



Tables



Step 6



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

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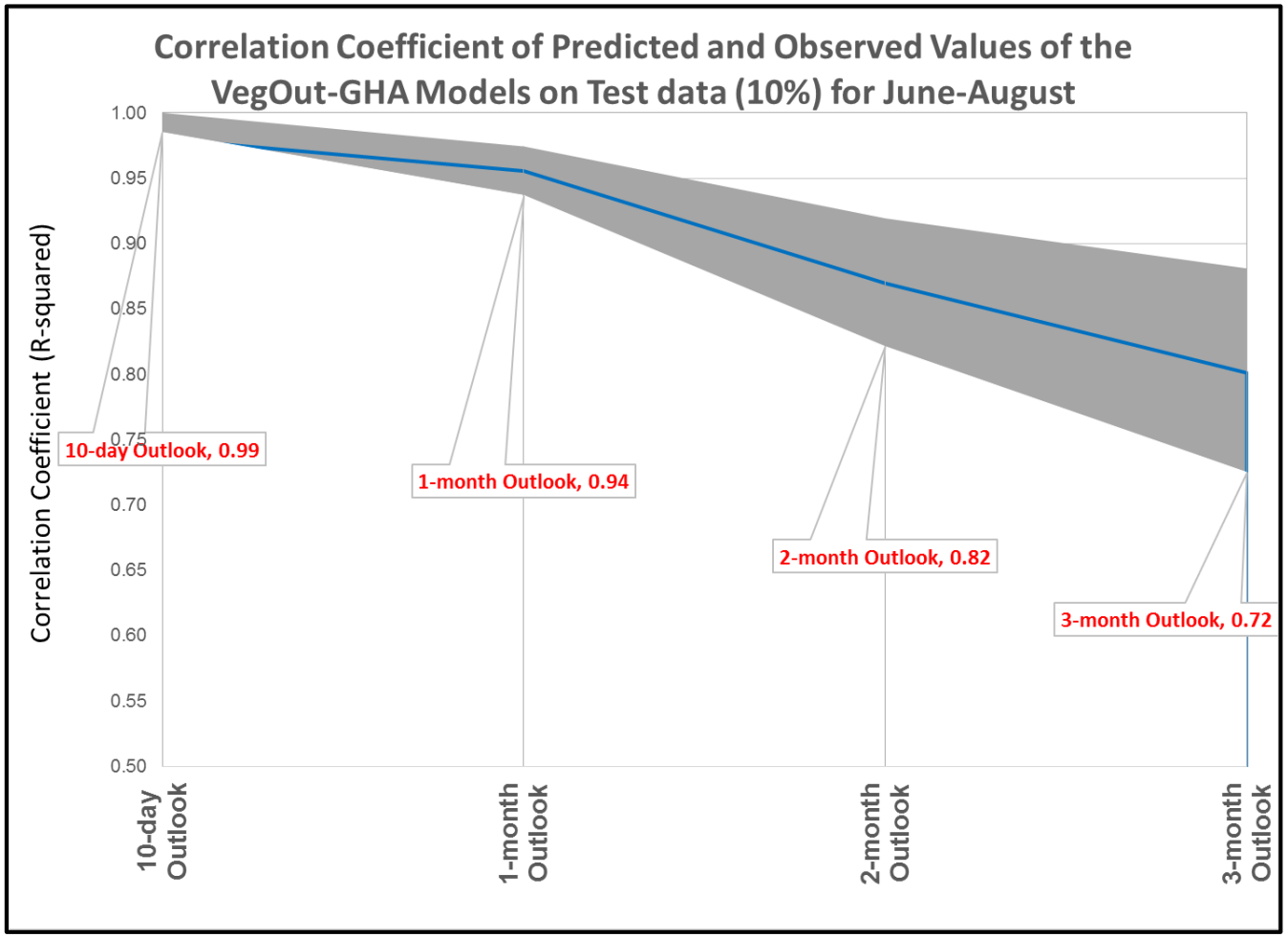
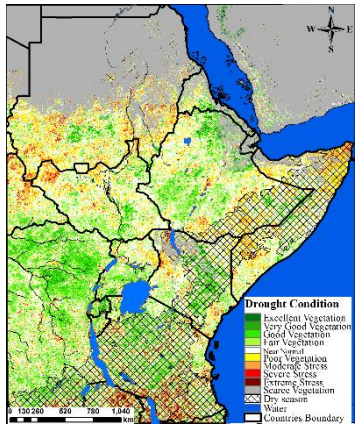
Rule 30: if … then

VegOut-GHA Model Evaluation on Test Data



May 21-31, 2002



Observed/Initial Condition

Vegetation Condition

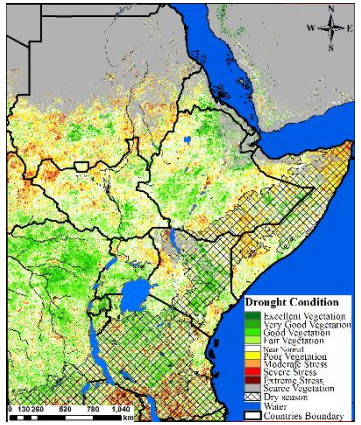
- Extreme Stress
- Severe Stress
- Moderate Stress
- Poor Vegetation
- Near Normal
- Fair Vegetation
- Good Vegetation
- Very Good Vegetation
- Excellent Vegetation
- Scarce Vegetation
- Dry Season
- Water
- Country Boundary

Difference Map

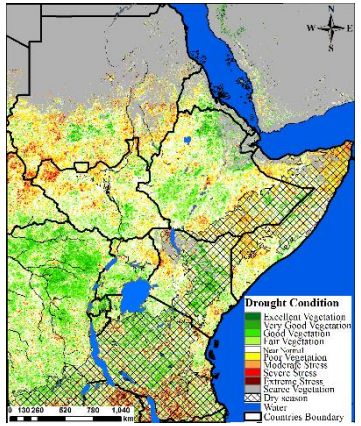
Predicted – Observed (+/- 1 STD)

- Over-predicted
- Similar
- Under-predicted

June 1-10, 2002



June 21-30, 2002



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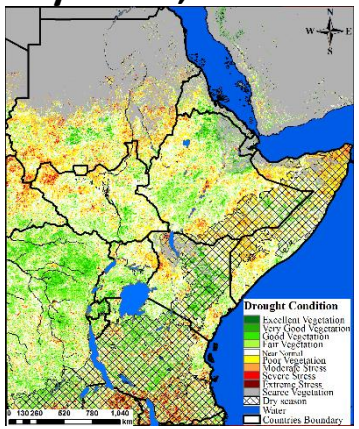
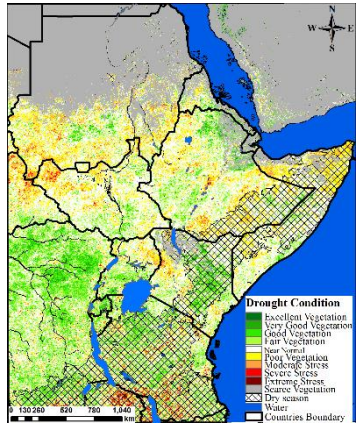
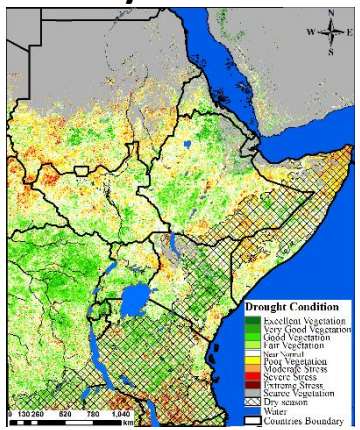


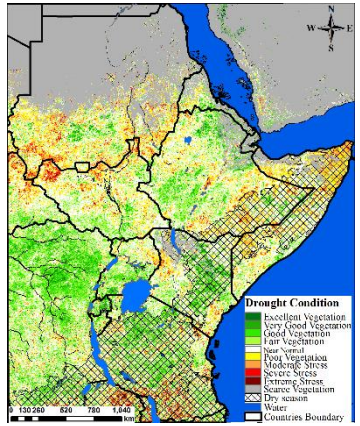
August 21-31, 2002



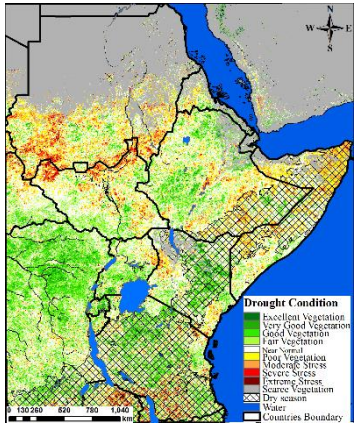
10-day outlooks



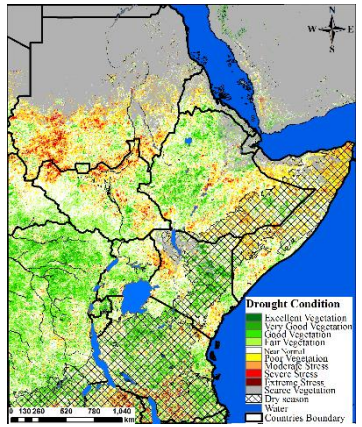
1-month outlook



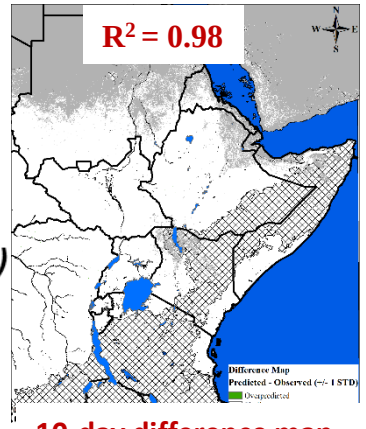
2-month outlook



3-month outlook

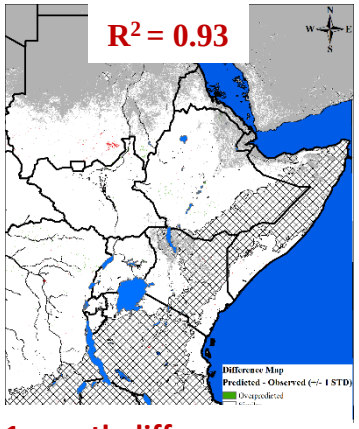


Observed SSG



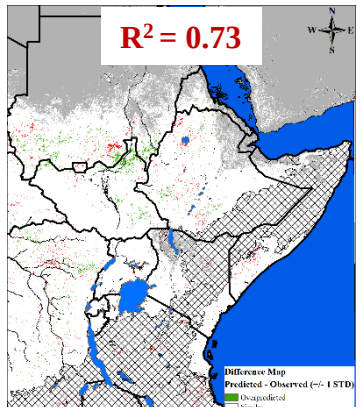
10-day difference map

Observed SSG



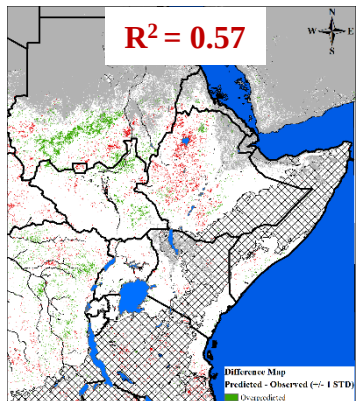
1-month difference map

Observed SSG



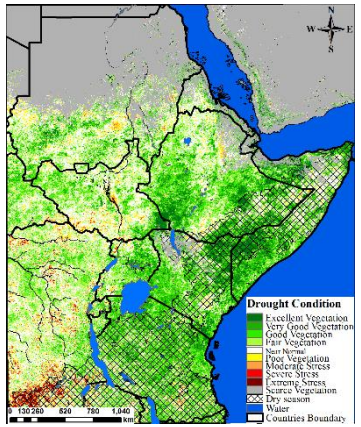
2-month difference map

Observed SSG



3-month difference map

May 21-31, 2007



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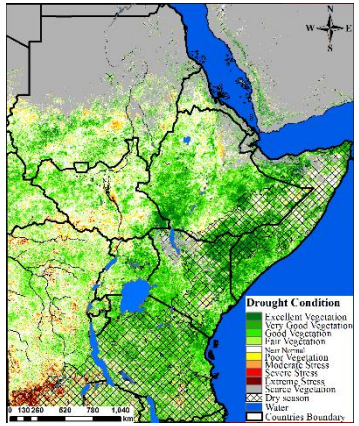

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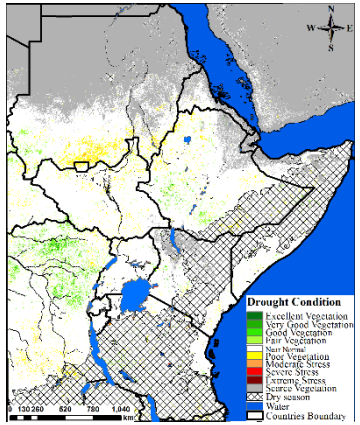
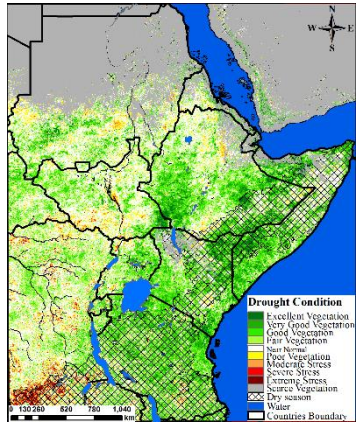
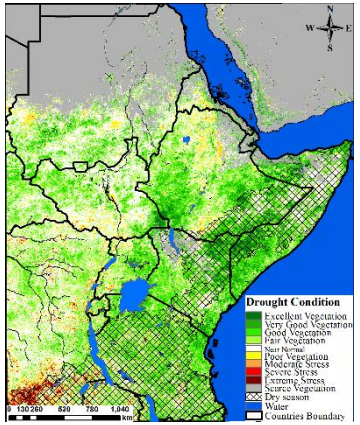


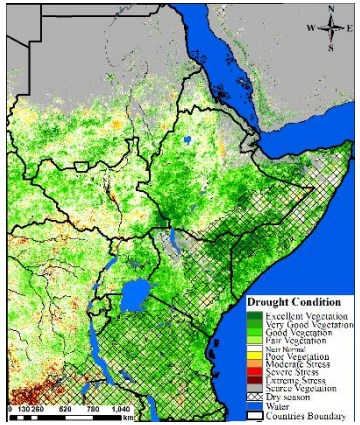
July 21-31, 2007



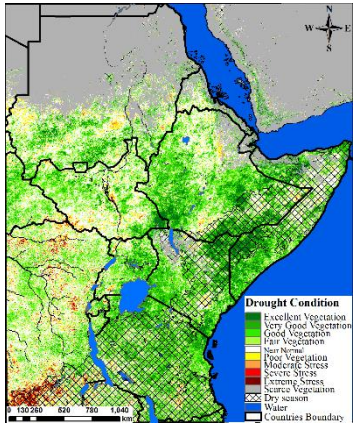
August 21-31, 2007



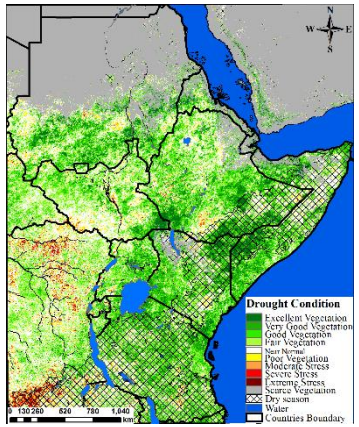
10-day outlooks



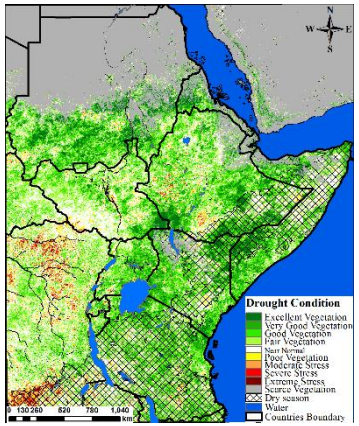
1-month outlook



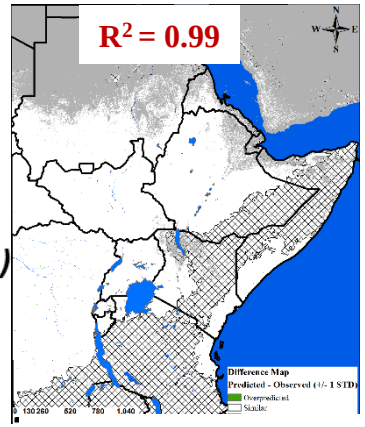
2-month outlook



3-month outlook

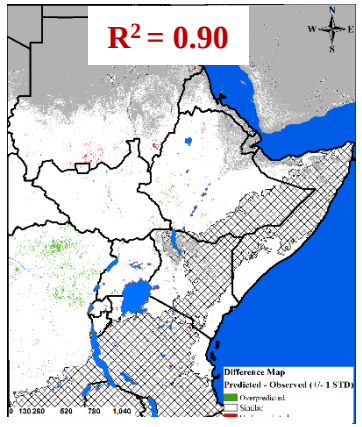


Observed SSG



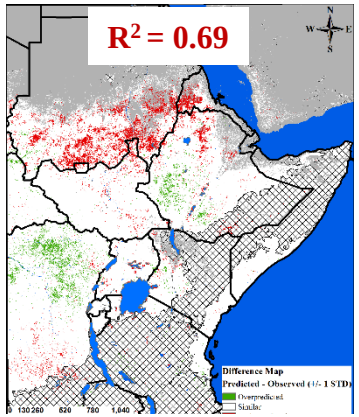
10-day difference map

Observed SSG



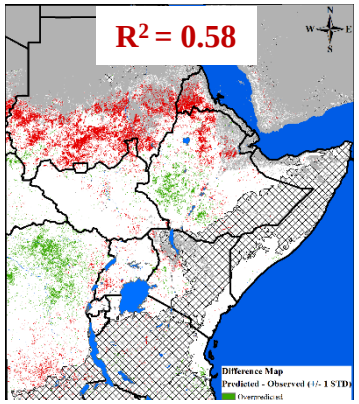
1-month difference map

Observed SSG



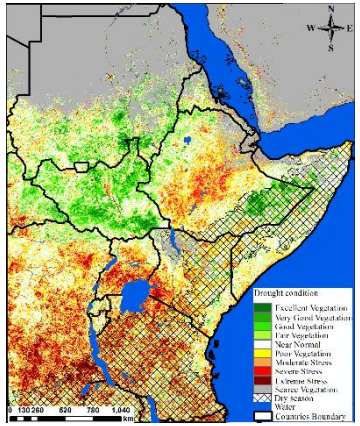
2-month difference map

Observed SSG



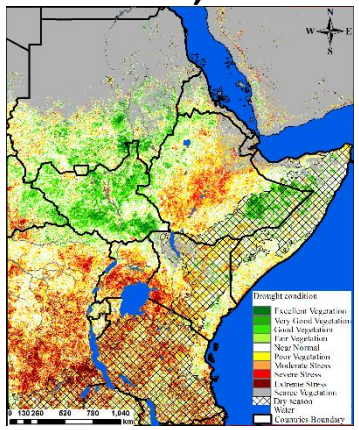
3-month difference map

May 21-31, 2015

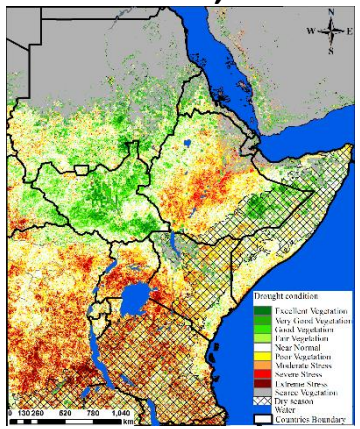


Observed/Initial Condition

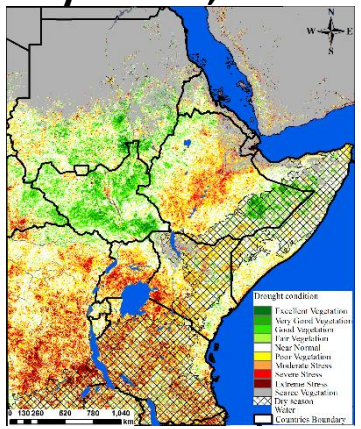
June 1 - 10, 2015



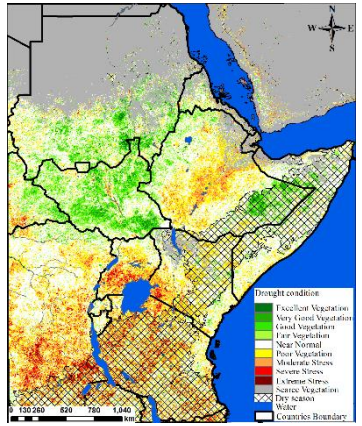
June 21 - 30, 2015



July 21 - 31, 2015



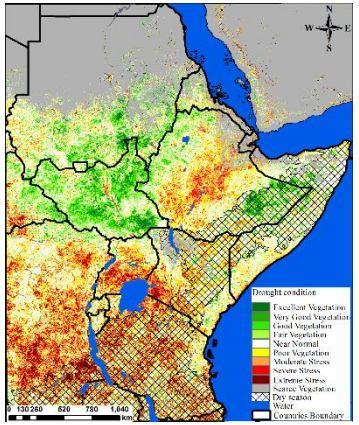
August 21 - 31, 2015



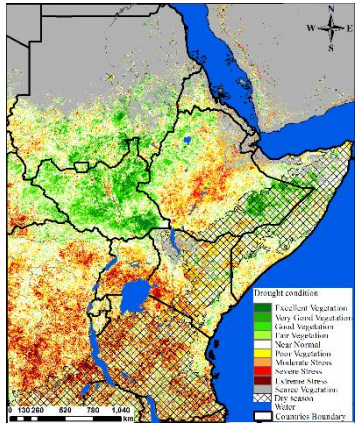
Vegetation Condition

- 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

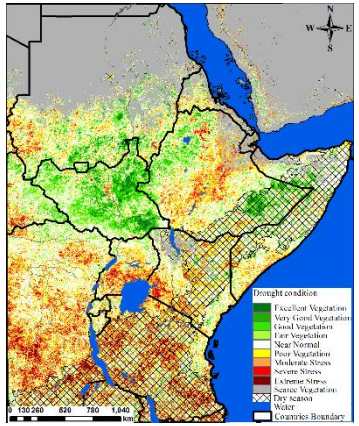
10-day outlooks



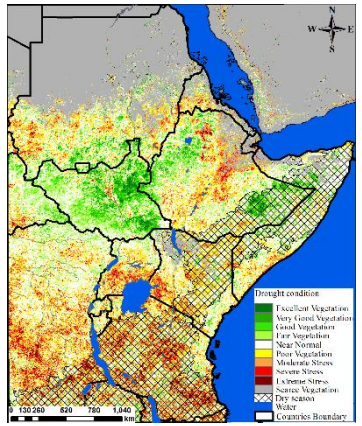
1-month outlook



2-month outlook



3-month outlook

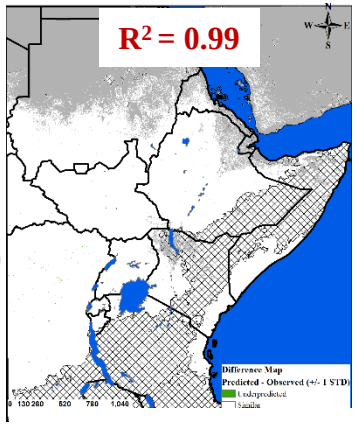


Difference Map

Predicted – Observed (+/- 1 STD)

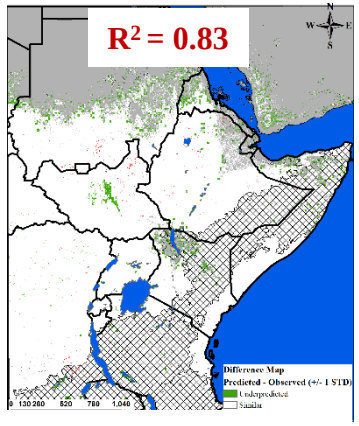
- Over-predicted
- Similar
- Under-predicted

Observed SSG



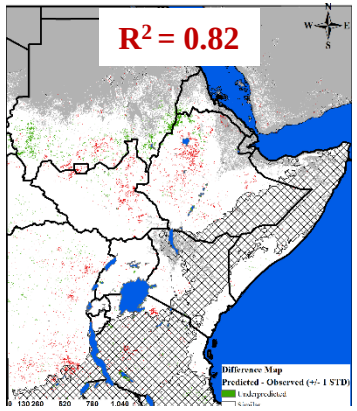
10-day difference map

Observed SSG



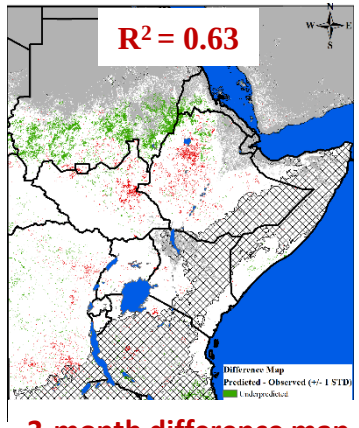
1-month difference map

Observed SSG



2-month difference map

Observed SSG



3-month difference map

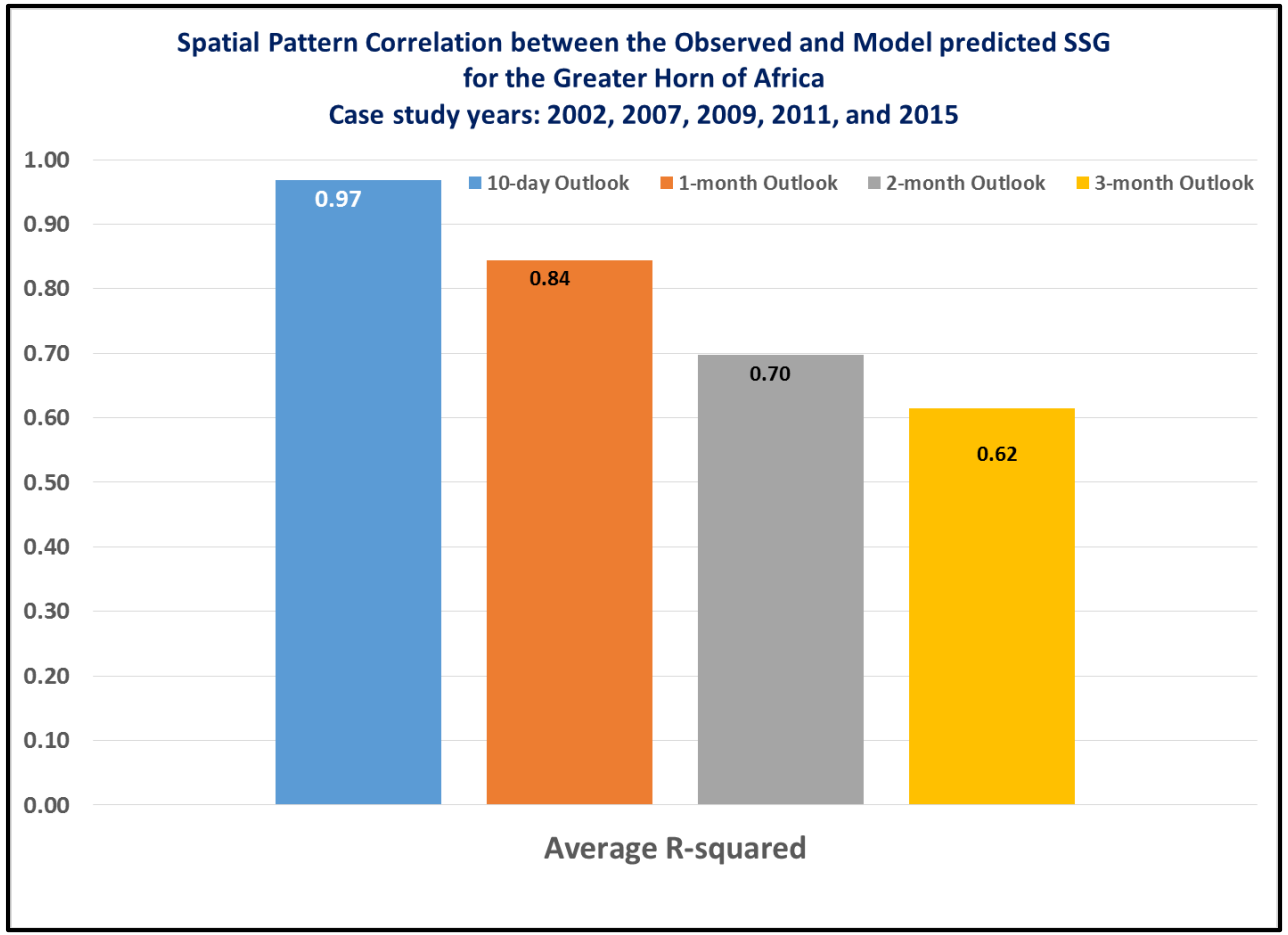
Spatial Pattern Correlation between the Observed and Model predicted SSG for the Greater Horn of Africa

Case study years: 2002, 2007, 2009, 2011, and 2015

Evaluation model performance using retrospective forecast

Year	Dekad	Coefficient of determination (R^2)			
		10-day Outlook	1-month Outlook	2-month Outlook	3-month Outlook
2002	3rd Dek_May	0.984	0.920	0.748	0.582
	3rd Dek_June	0.982	**0.452**	0.714	0.576
	3rd Dek_Jul	0.978	0.887	0.733	0.605
	3rd Dek_Aug	0.968	0.897	0.785	0.658
2007	3rd Dek_May	0.978	0.880	0.582	**0.376**
	3rd Dek_June	0.968	0.640	**0.493**	**0.448**
	3rd Dek_Jul	0.962	0.824	0.674	0.598
	3rd Dek_Aug	0.976	0.912	**0.440**	0.741
2009	3rd Dek_May	0.984	0.914	0.780	0.626
	3rd Dek_June	0.986	0.910	0.745	0.612
	3rd Dek_Jul	0.980	0.889	0.745	0.677
	3rd Dek_Aug	0.982	0.927	0.824	0.771
2011	3rd Dek_May	0.982	0.878	0.669	0.476
	3rd Dek_June	**0.771**	0.830	0.630	0.557
	3rd Dek_Jul	0.970	0.859	0.707	0.621
	3rd Dek_Aug	0.976	0.876	0.733	0.666
2015	3rd Dek_May	0.986	0.935	0.803	0.610
	3rd Dek_June	0.986	0.600	0.752	0.604
	3rd Dek_Jul	0.980	0.904	0.778	0.702
	3rd Dek_Aug	0.984	0.941	0.610	0.797
Average		0.97	0.84	0.70	0.62

Spatial Pattern correlation = Grid by grid comparison of observed and model predicted values



Validation – Work still in Progress

USE OF CROP PRODUCTION DATA

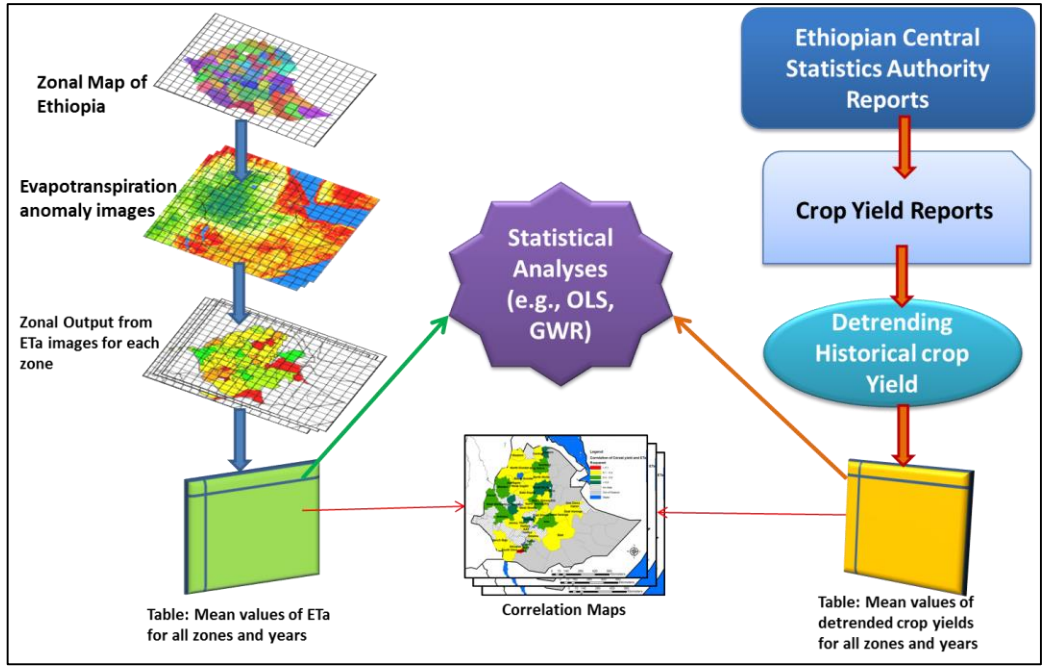
Comparing Zonal-Level Crop Yields to Drought Pattern of the VegOut-GHA

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

NASA-GHA Project Team: UNL, JHU, UCSB/CHG, USGS, UWM, IRI/CU, and JPL/NASA

Chris Poulsen, GIS Manager, NDMC/UNL

John Swigart, Geospatial Analyst, NDMC/UNL

Karin Callahan, GIS/Remote Sensing Specialist, USGS

Gabriel Senay, USGS

My daughter (Mirikate) is the biggest boss in my life!

My Family

- Betlehem
- Nigus/King
- Mirikate/Kate

THANK YOU

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