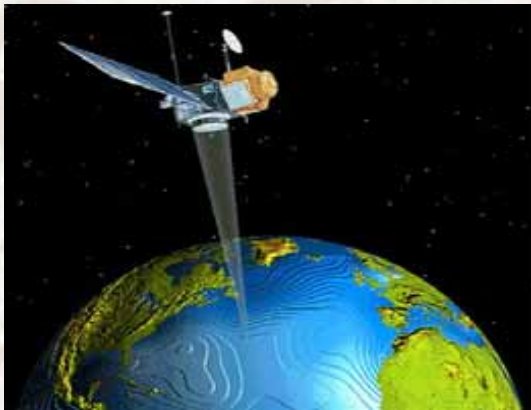


# Remote Sensing and Drought Monitoring

## *An Overview, Options for Mali, and Future Directions*



Dr. Brian Wardlow

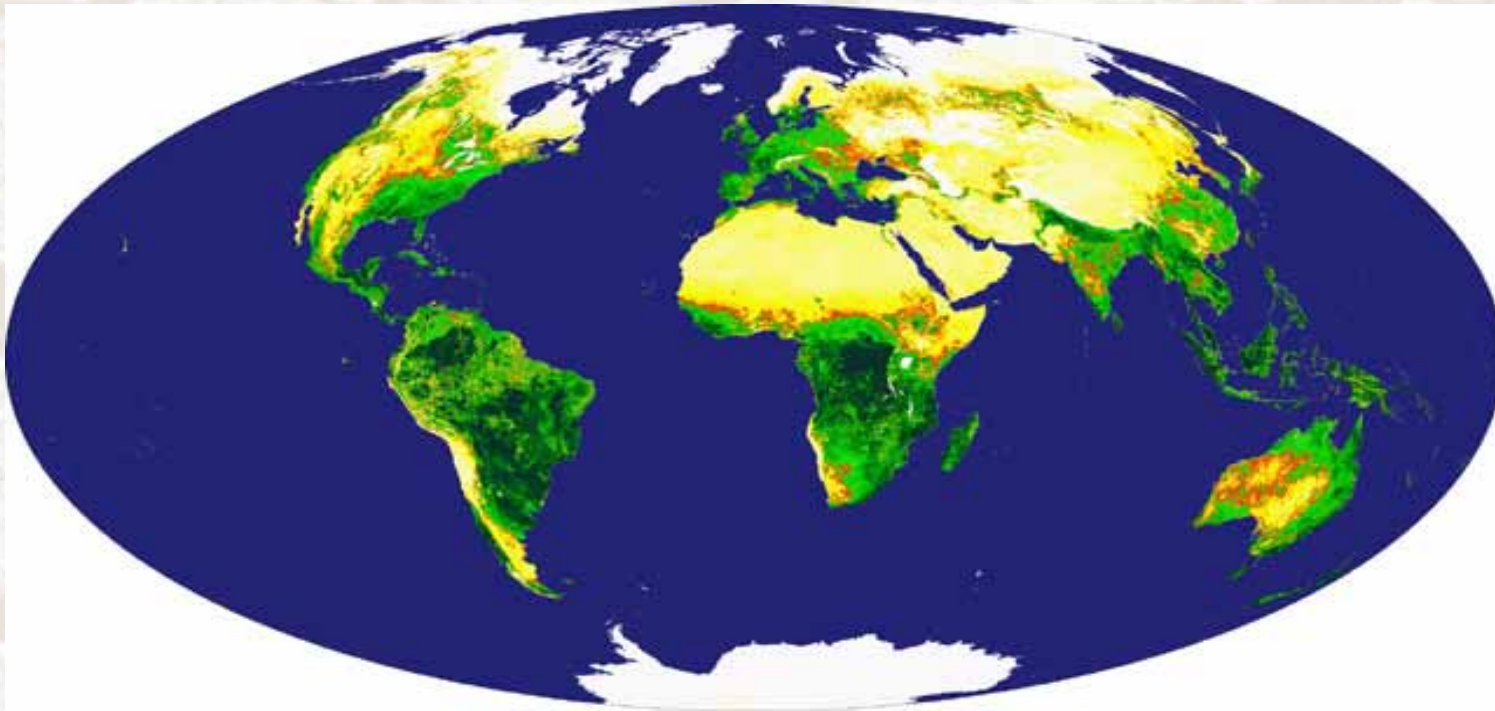
Assistant Professor  
Remote Sensing Specialist  
National Drought Mitigation Center  
University of Nebraska-Lincoln



Drought Monitor Workshop  
Bamako, Mali  
September 14-17, 2009

# Remote Sensing for Environmental Monitoring

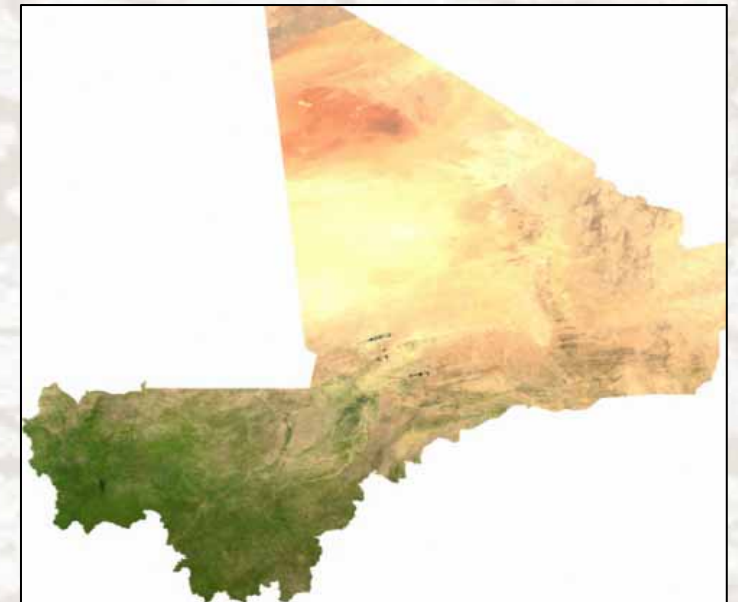
Satellite-based remote sensing has been widely used over the past 20+ years for national to global-scale many environmental monitoring activities, including drought.





# Advantages of Remote Sensing for Drought Monitoring

1. Spatial continuous measurements across large geographic areas.
  - Important in locations where weather stations or other ground observations (human) are sparse or non-existent.
2. Frequent revisit time for image acquisition
  - Several satellites acquire image data every 1-2 days or a 1-2 week basis for same location.
3. Historical record of conditions
  - Several instruments (AVHRR and Landsat) provide 20+ years of information with some newer sensors (MODIS) approaching 10+ years of observations.

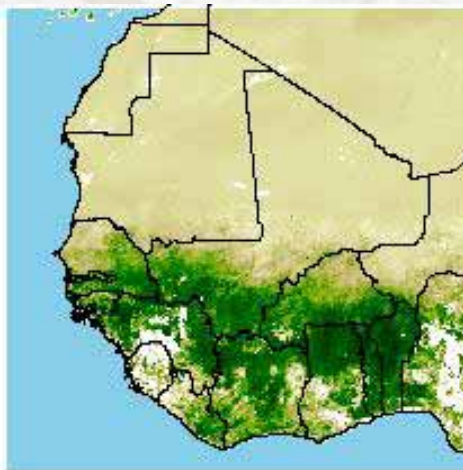


Satellite image of relative vegetation greenness for Mali.

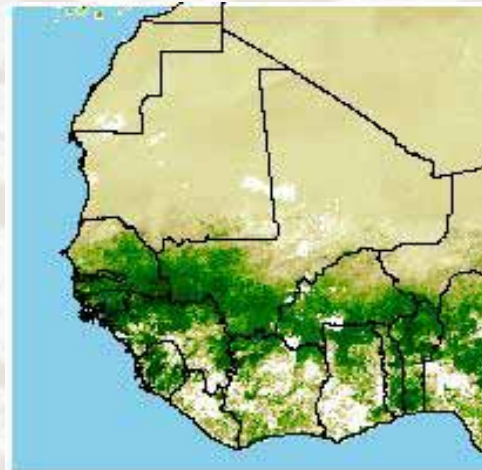
# Ideal Remote Sensing Data Characteristics for Drought Monitoring

1. **Operational data production** – routinely produce the same data products at a set time interval.

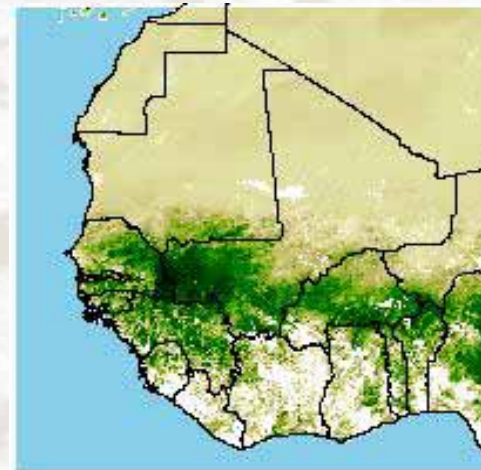
Ex. – Production a vegetation condition map each dekad.



July 2009 – Dekad 2

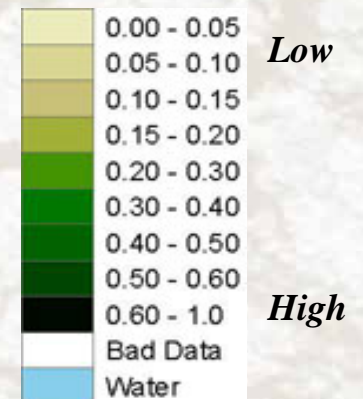


July 2009 – Dekad 3



August 2009 – Dekad 3

## Greenness





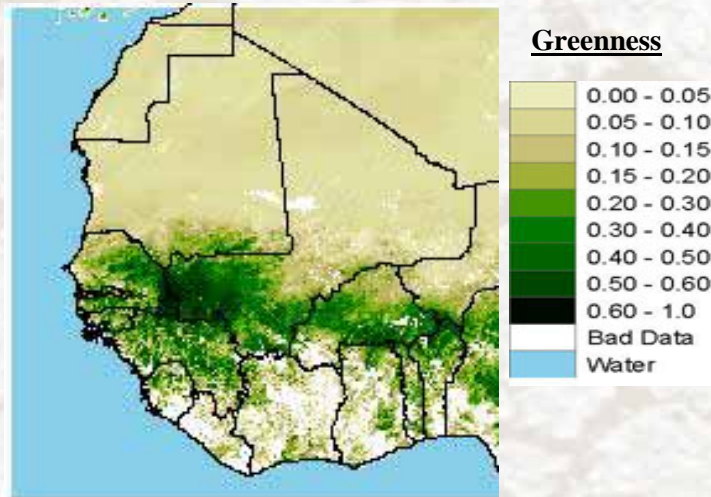
# Ideal Remote Sensing Data Characteristics for Drought Monitoring

## 2. Anomaly, Percent of Normal, Change, or Ranking Maps

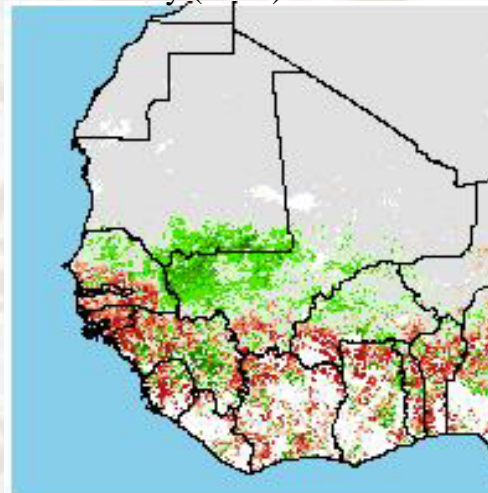
Provide historical context of how current conditions compare to the historical conditions for a specific location and time during the year.

- Easier to differentiate moderate, severe, and extreme drought events.

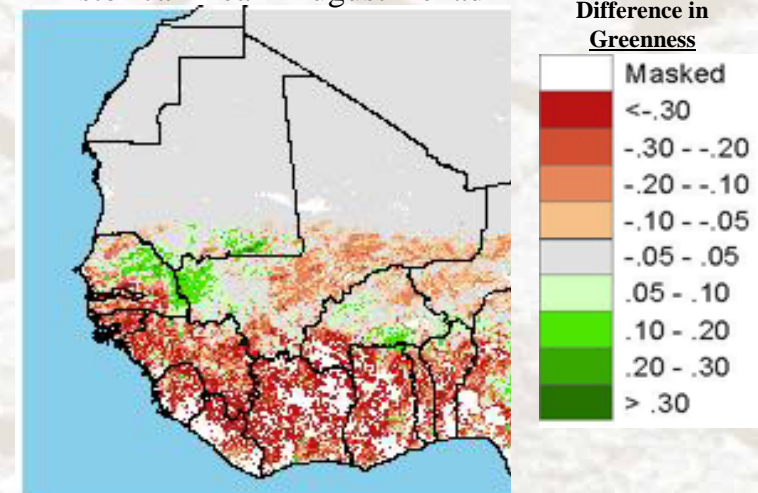
Current Greenness  
August (2009) Dekad 1



Difference in Greenness from  
July (2009) Dekad 3



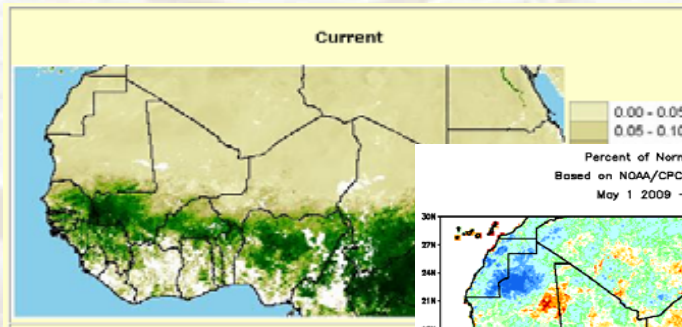
Difference in Greenness from  
Historical Mean August Dekad 1



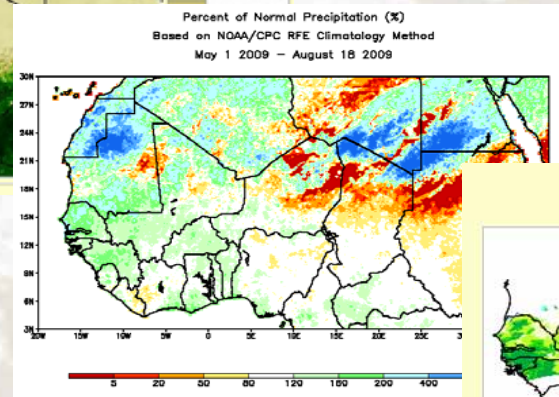
# Ideal Remote Sensing Data Characteristics for Drought Monitoring

## 3. Data easy accessible and in multiple formats

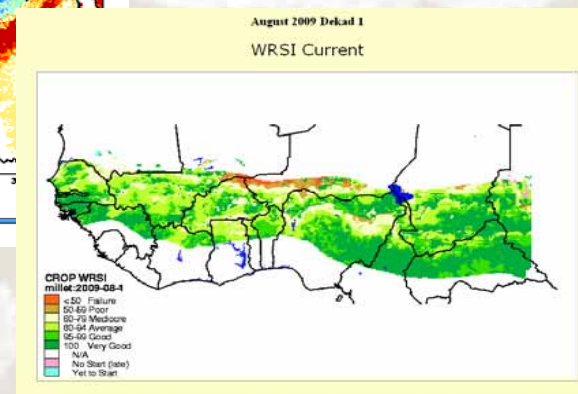
- digital data in analysis using GIS and computers
- graphical maps that can be downloaded and printed for visual analysis



Vegetation Greenness Map



Precipitation Maps



Water Requirement Satisfaction Index Map



# Ideal Remote Sensing Data Characteristics for Drought Monitoring

## 4. Evaluation of the Information's Accuracy for Your Local Area

### *Assess Accuracy for:*

- 1) multiple locations across your country or region
- 2) multiple years (drought and non-drought periods)
- 3) spatial gradients between drought and non-drought areas
- 4) trends over time

### *Resources:*

- Expert opinion
  - climatology, meteorology, agriculture, water resources, and natural resources/ecology
- Local feedback
- Ground measurement
  - crop/rangeland conditions, meteorological and surface water observations, and
- Comparison with other drought index data and maps

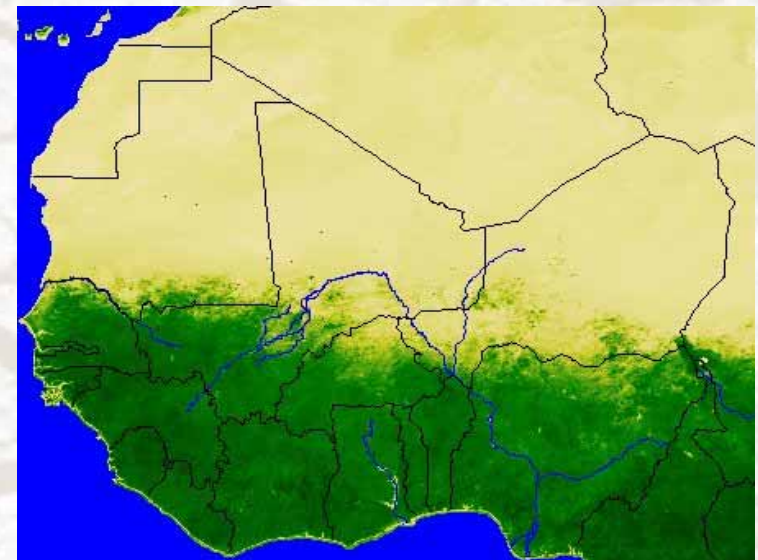
# Traditional Remote Sensing Information Used for Drought Monitoring

## Normalized Difference Vegetation Index (NDVI)

Quantitative indicator of the relative abundance and activity of green vegetation.

Well correlated with several biophysical characteristics of vegetation:

- leaf area index (LAI)
- % green cover
- green biomass
- chlorophyll content



Annual Maximum NDVI (or Greenness) Image



# ***NDVI* – Why is it an Indicator of Vegetation Health?**

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

**NIR (Near-Infrared)** energy sensed from vegetation is controlled by the plants internal leaf structure.

LOW NIR = stressed or non-green vegetation (wilting)

HIGH NIR = healthy green vegetation

**Red** energy detected from vegetation is controlled by the vegetation's chlorophyll content.

LOW Red = healthy green vegetation absorbs visible red energy

HIGH Red = stressed or non-green vegetation reflects red energy

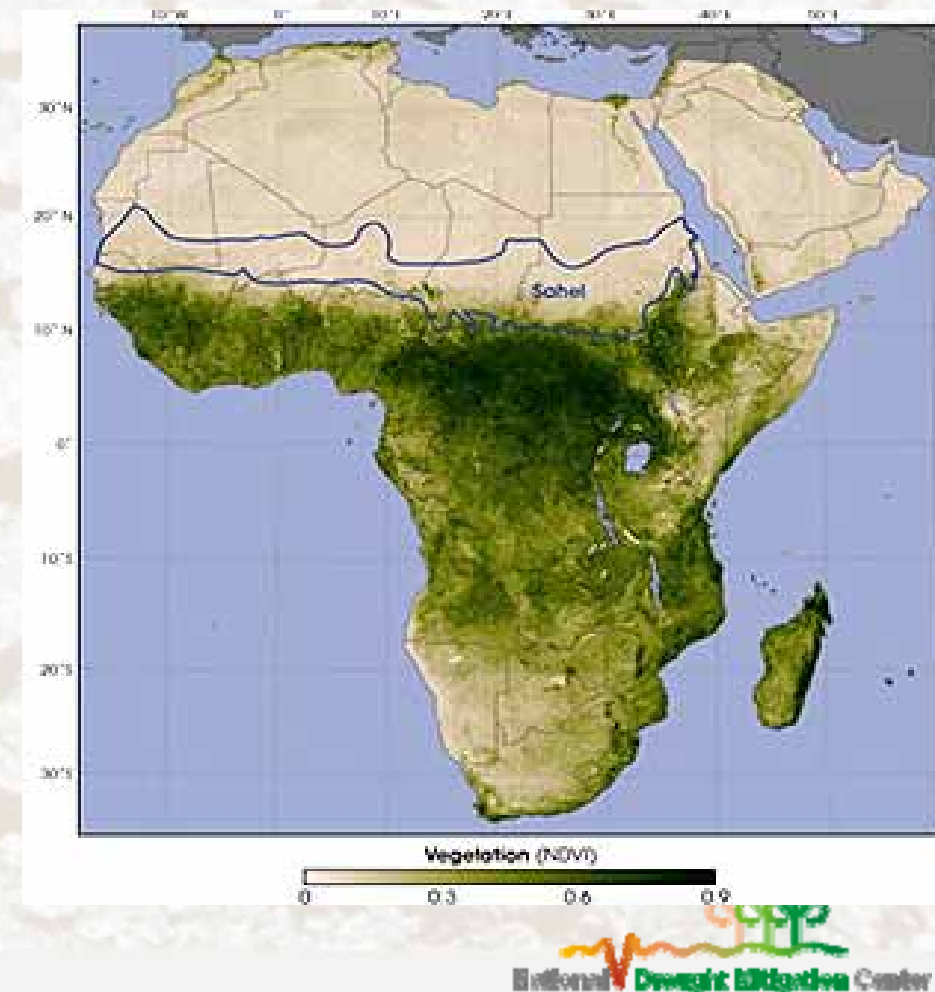
**NDVI** values ranging from -1 to +1.

HIGH NDVI values = healthy, green vegetation (typical range of vegetation values from 0.2 - .08, with values > 0.5 indicative of denser vegetation)

LOW NDVI values = stressed or non-green vegetation

# NDVI (Greenness Product) and AVHRR

- The Advanced Very High Resolution Radiometer (AVHRR) instrument from the National Oceanic and Atmospheric Administration (NOAA) has produced a 20+ year historical record of global NDVI observations.
- NDVI maps at a 8-km spatial resolution updated at weekly, bi-weekly, dekadal, and monthly time intervals dating back to 1982.
- Widely used for drought monitoring and other types of environmental assessments (e.g., ecological studies and crop production).





# Vegetation Health Index (VHI)

**VHI** estimates vegetation health (condition) based on combination of :

**1) *vegetation greenness***

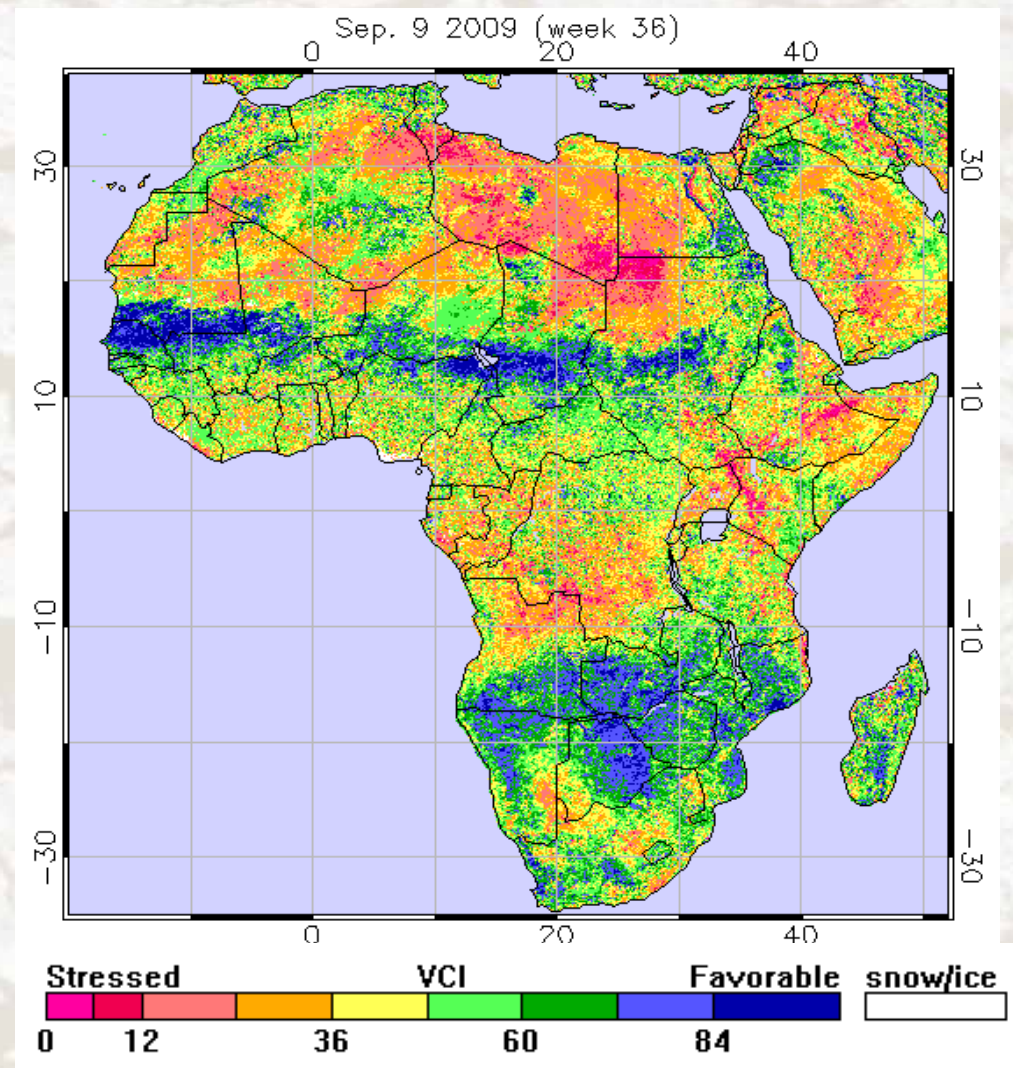
(Normalized Difference Vegetation Index, NDVI)

**2) *temperature***

(Brightness Temperature, BT).

VHI Data Characteristics:

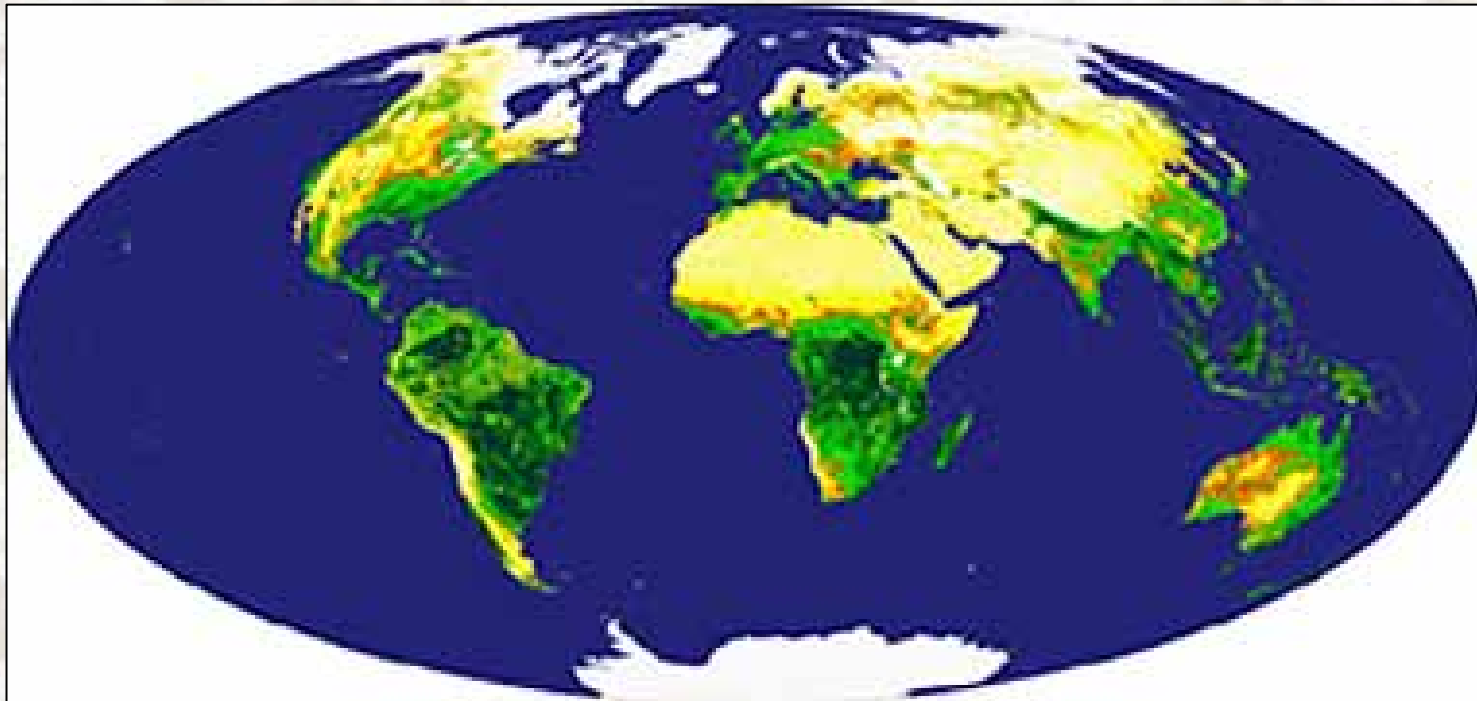
- 8-km spatial resolution
- weekly updates
- 2004 - present



[http://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh\\_currentImage.php](http://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_currentImage.php)

## Other Global NDVI Data Sets

- Large-area NDVI data sets are also available from other satellite-based remote sensing instruments (MODIS, SPOT Vegetation, and MERIS), but they lack a long historical record of information.





# Traditional Remote Sensing Information Used for Drought Monitoring

## Rainfall Estimate (RFE)

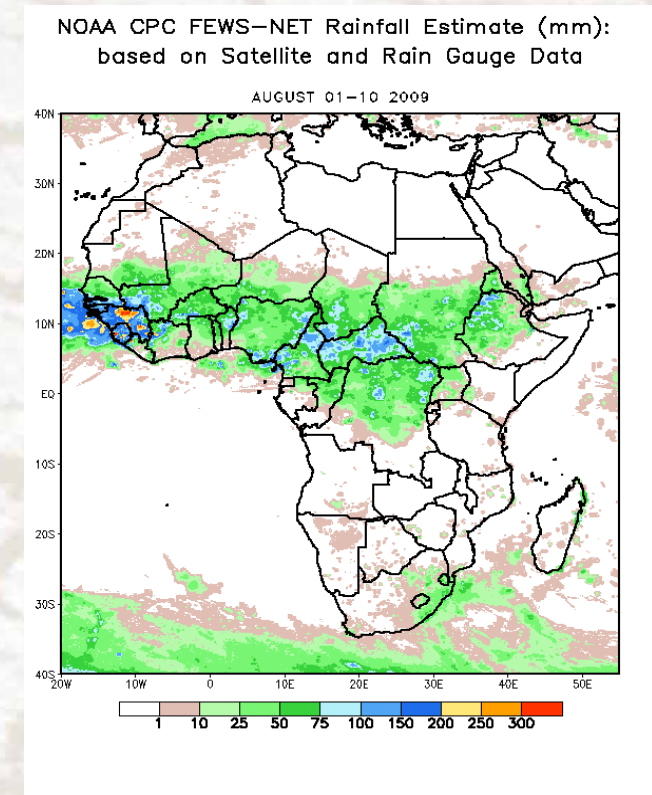
Uses a combination of satellite-based observations (cloud temperature and cold cloud duration) and ground-based rain gauge information.

- RFEs updated at multiple time intervals
  - daily
  - dekad
  - weekly
  - monthly

## *Satellites:*

- Meteosat (used since 1995)
- Special Sensor Microwave/Imager (SSM/I)\*\*
- Advanced Microwave Sounding Unit (AMSU)\*\*

\*\*Implemented in 2000.



# Operational Remote Sensing Products for Mali

---



# Famine Early Warning System (FEWS) Network

## Remote Sensing Data Resources for Mali

### FEWS/NOAA Data:

- Set of rainfall estimates (RFE) and anomalies
- Short- & long-term forecasts

### FEWS/USGS Data:

- Vegetation condition data sets
- Soil Moisture Index
- RFE data
- Standardized Precipitation Index (SPI)

The screenshot shows the FEWS NET website interface. At the top, there are language options (Español, Français, Português) and navigation links (Home, About, E-mail Updates, Contact Us). The main header features the USAID logo and the FEWS NET logo. Below this is a navigation menu with categories: Region & Country Centers, Agro-climatic Monitoring, Markets & Trade, Livelihoods, and Product Catalogue. A dropdown menu for 'Agro-climatic Monitoring' is open, showing options for 'More from FEWS/NOAA' and 'More from FEWS/USGS'. Below the menu is a 'Latest Headlines' section with a red banner about 'kiremt rains could further exacerbate'. A 'Near-term Outlook' section is visible, with a sub-section for 'Estimated food security conditions, 3rd Quarter 2009 (July-September)'. A map of Africa is displayed with a color-coded legend for food security severity: Generally Food Secure (green), Moderately Food Insecure (yellow), Highly Food Insecure (orange), Extremely Food Insecure (red), Famine (dark red), and No Data (grey). Below the map is a 'Price Watch' section and an 'Exec Overview Brief' section. At the bottom, there are sections for 'West Africa' (Mauritania) and 'East Africa' (Tanzania) with recent alerts and news items.

<http://www.fews.net/Pages/default.aspx>

# FEWS/U.S. Geological Survey (USGS)

## *Maps and Data*





## USGS - EROS Early Warning and Environmental Monitoring Program

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[Search Early Warning Network](#)

*Click on the region/topic you want to visit*



Global Datasets



Africa FEWS NET



Afghanistan FEWS NET



Central America MFEWS



Haiti FEWS NET



South Asia Rainfall



Mexico Rain Dry Days



US EWEM



South Central Asia

<http://earlywarning.usgs.gov/?l=en>



The Famine Early Warning Systems Network (FEWS NET) is to strengthen the abilities of foreign countries and regional organizations to manage risk of food provision of timely and analytical early warning and vulnerability information. [Read More...](#)

### Current Browse Graphics

#### Choose an Image Type:

##### Dekadal:

- NDVI (Normalized Difference Vegetation Index)
- NDVI-17
- RFE (Rainfall Estimate)
- RFE Anomaly -- Malaria
- SPI (Standardized Precipitation Index)
- Moisture Index
- Moisture Index/Soil Water Index Anomaly
- BERM (Basin Excess Rainfall Map)
- Inter-Tropical Front (ITF) Position
- Croplands WRSI
- Rangelands WRSI
- Seasonal NDVI & Rainfall Charts

##### Daily:

- Past 6 days RFE & Next 6 days Forecast
- Daily 10-Day RFE Anomaly -- Malaria
- Daily 10-Day Moisture Index
- Daily 10-Day Soil Water Index
- Daily 30-Day Rain and Dry Days
- Daily Runoff and Anomaly
- Daily WRSI

Several operational products for each dekad.

Custom maps and data available for different regions of Africa.

#### Choose an Extent:



Africa (continental)



West Africa

- AVHRR
- MODIS



East Africa



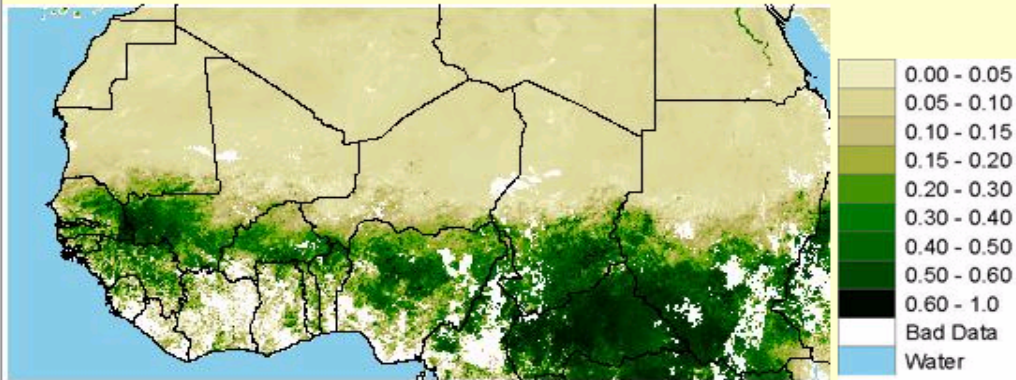
Southern Africa

- AVHRR
- MODIS

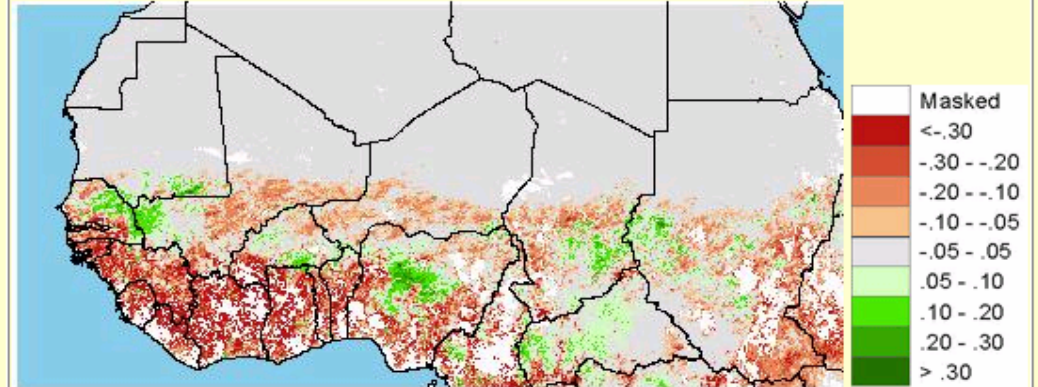


# NDVI (Vegetation Greenness)

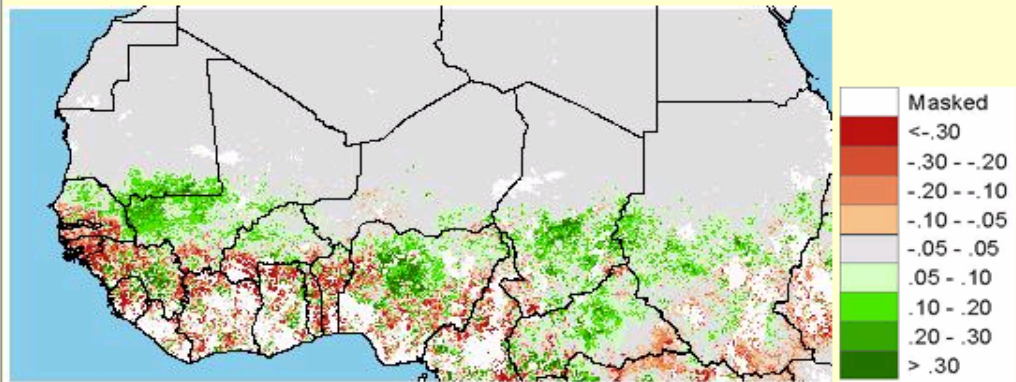
Current



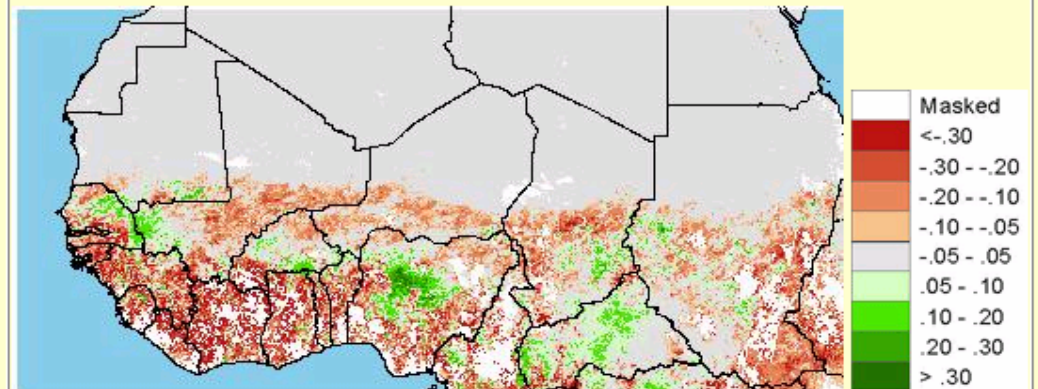
Current - Long Term Mean



Current - Previous



Current - Short Term Mean

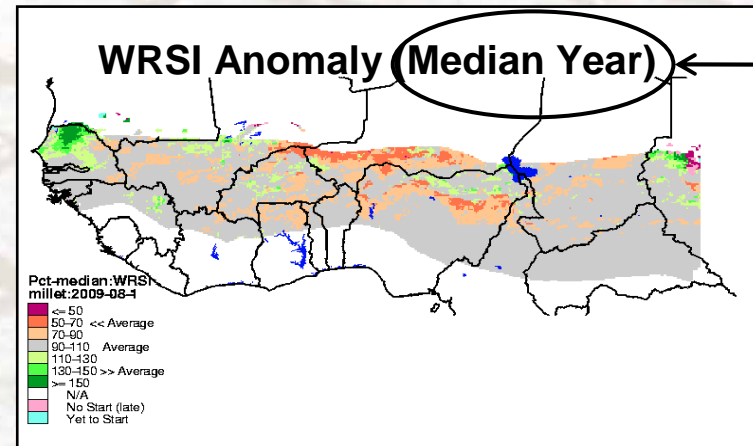
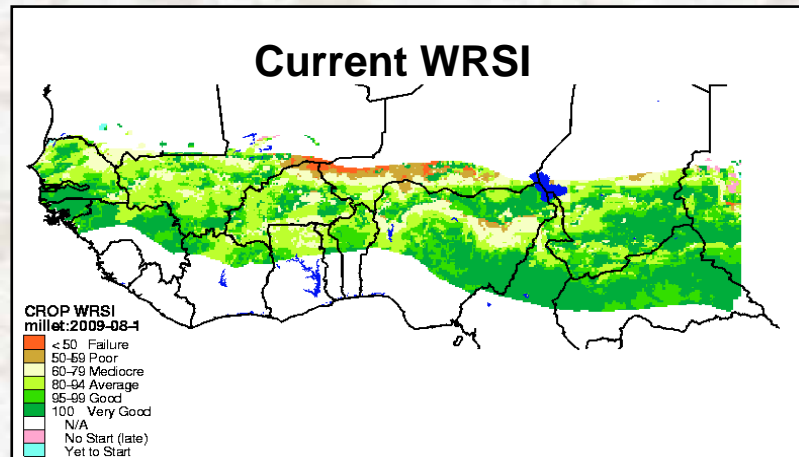


## Data Characteristics:

- 8-km spatial resolution
- 5-year of NDVI observations (2005 – present)
- Long-term mean: 1982 to 2008
- Short-term mean: 2003 to 2008

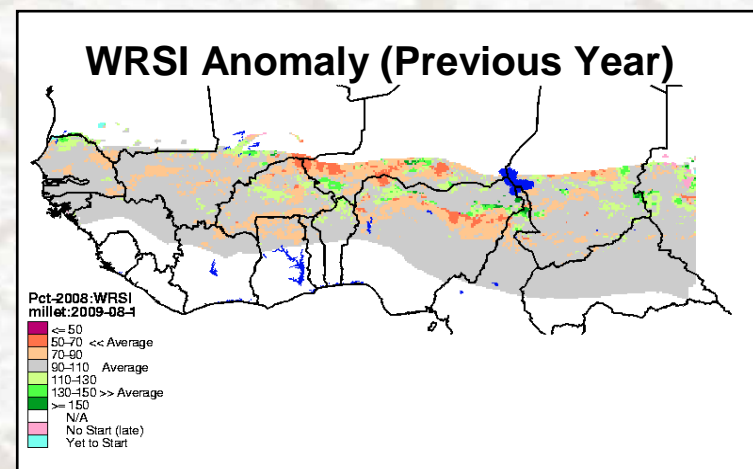
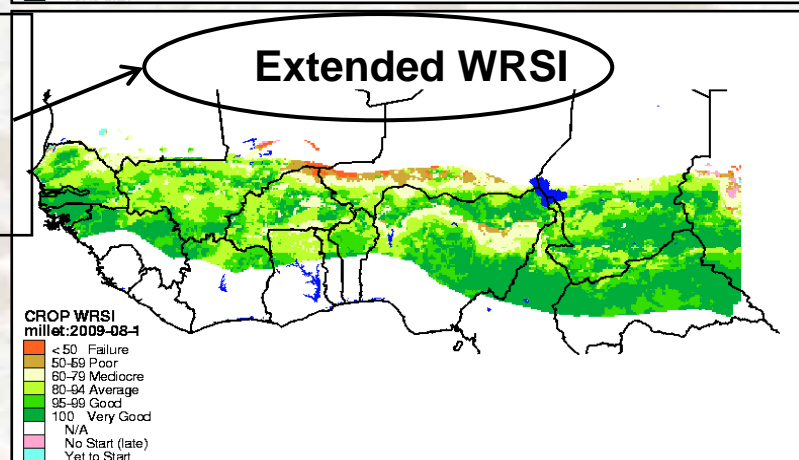
# Water Requirement Satisfaction Index (WRSI)

## Cropland (Millet)



Median year span:  
1996 – 2008

Forecast estimate of WRSI at the end of the growing season.

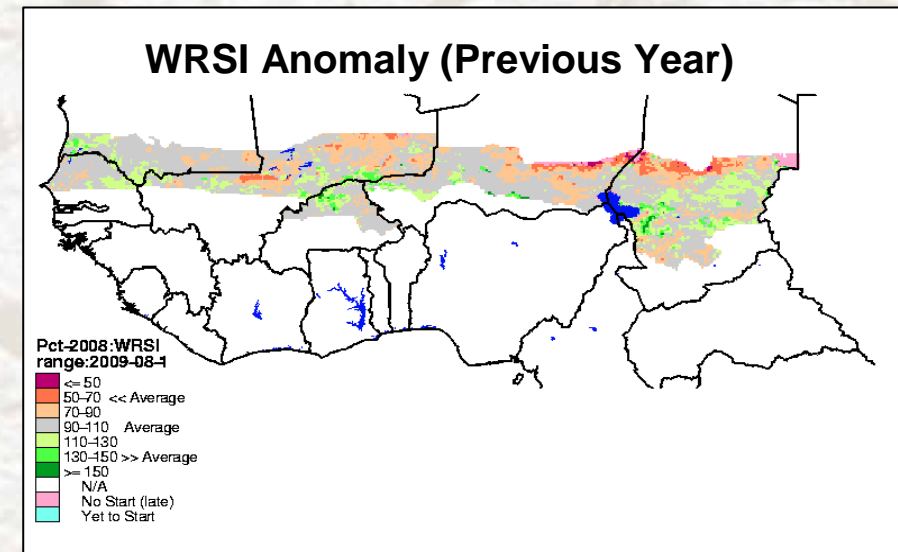
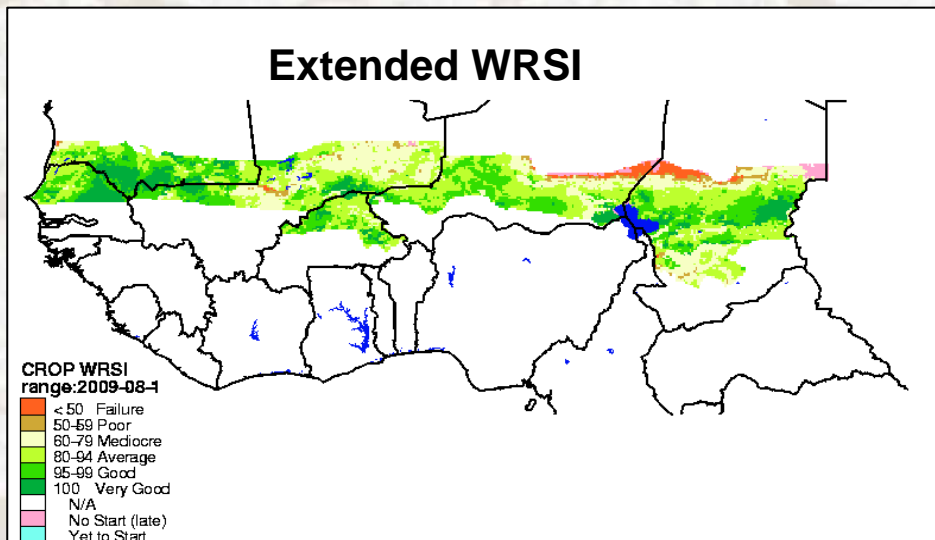
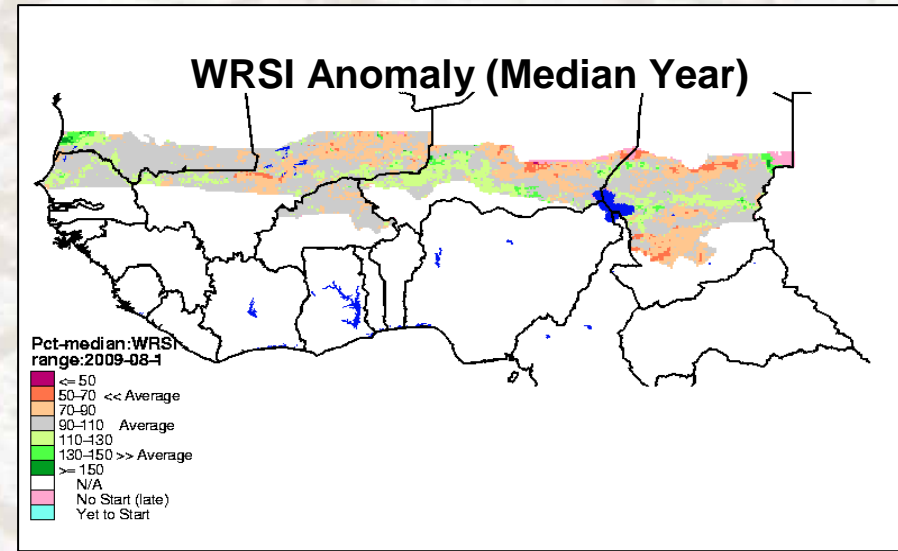
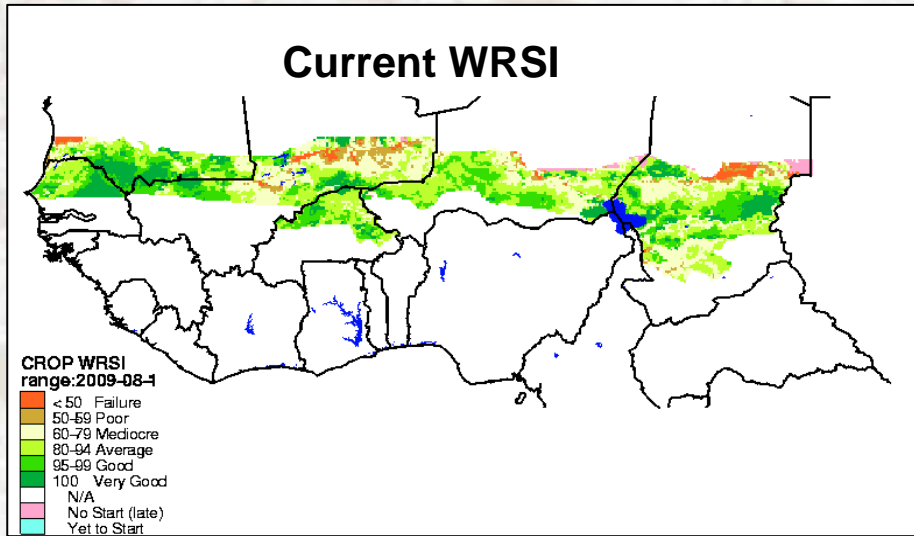


WRSI is an indicator of crop performance based on the availability of water to the crop during the growing season. Based on the water supply and demand of a crop.



# Water Requirement Satisfaction Index (WRSI)

## Rangeland

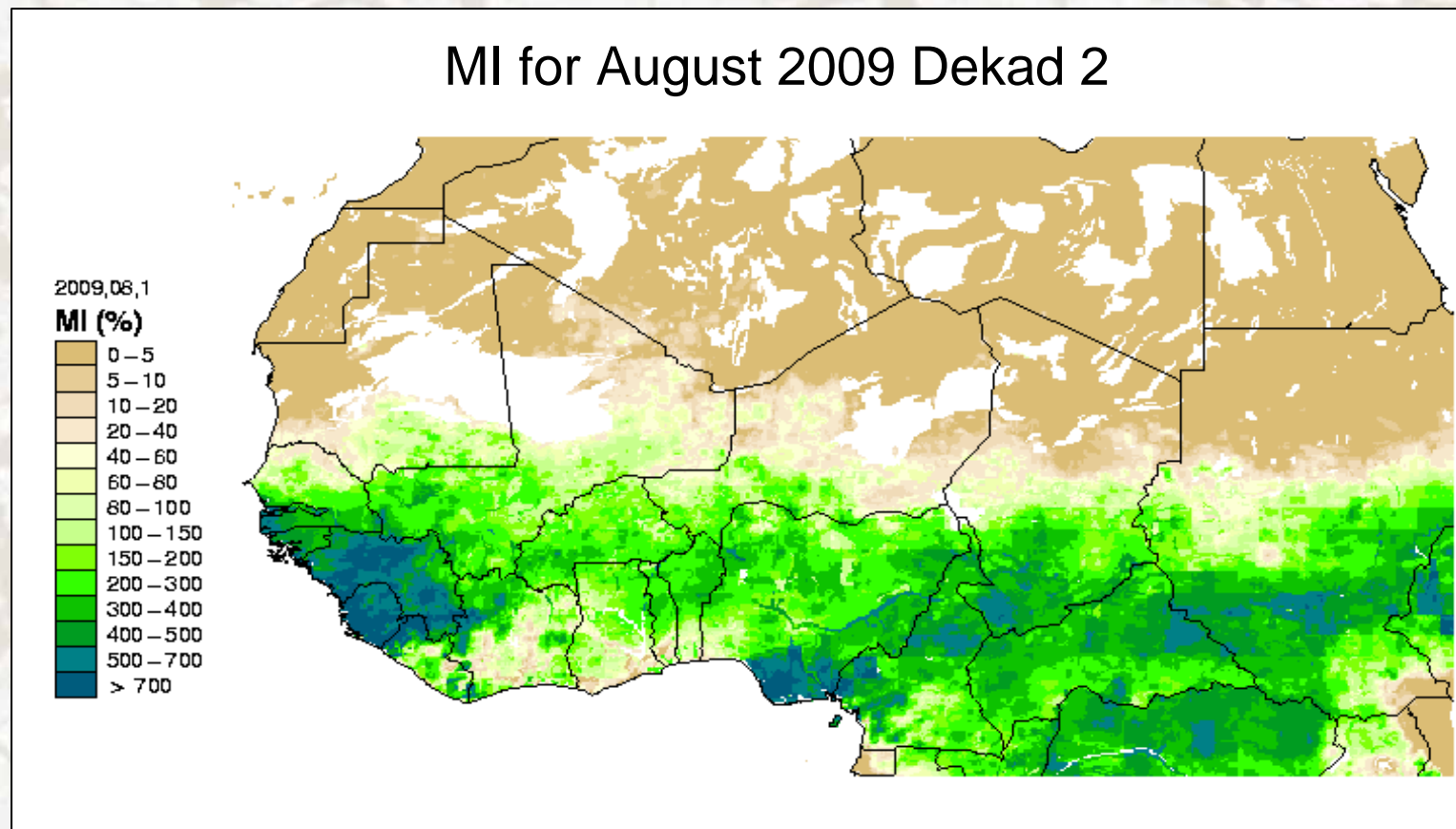


# Moisture Index (MI)

The MI is an agro-meteorological indicator defined by a simple 'supply/demand ratio' that is presented as a percentage.

Calculation of MI considers:

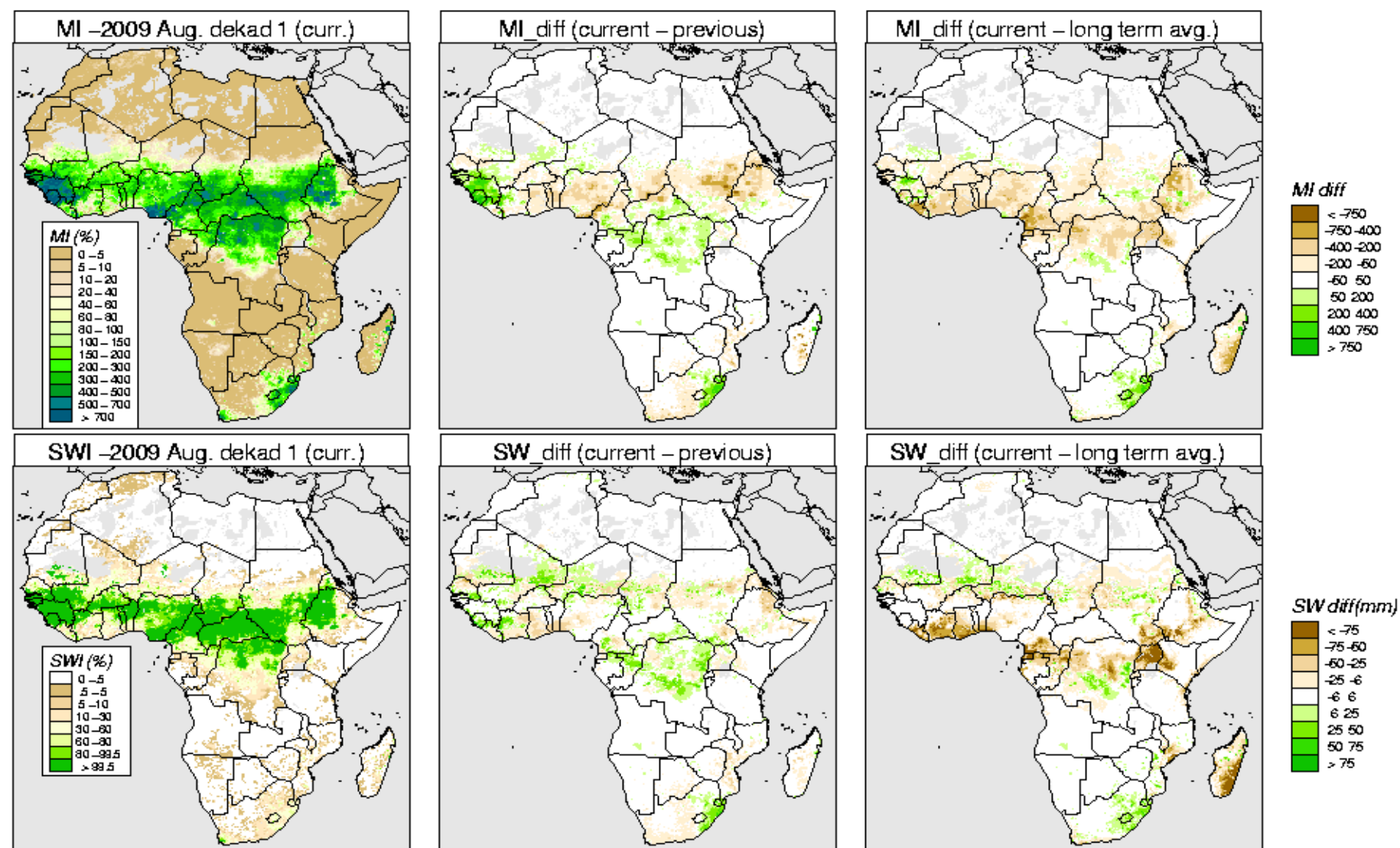
- 1) recent rainfall
- 2) available soil water
- 3) potential evapotranspiration (PET)





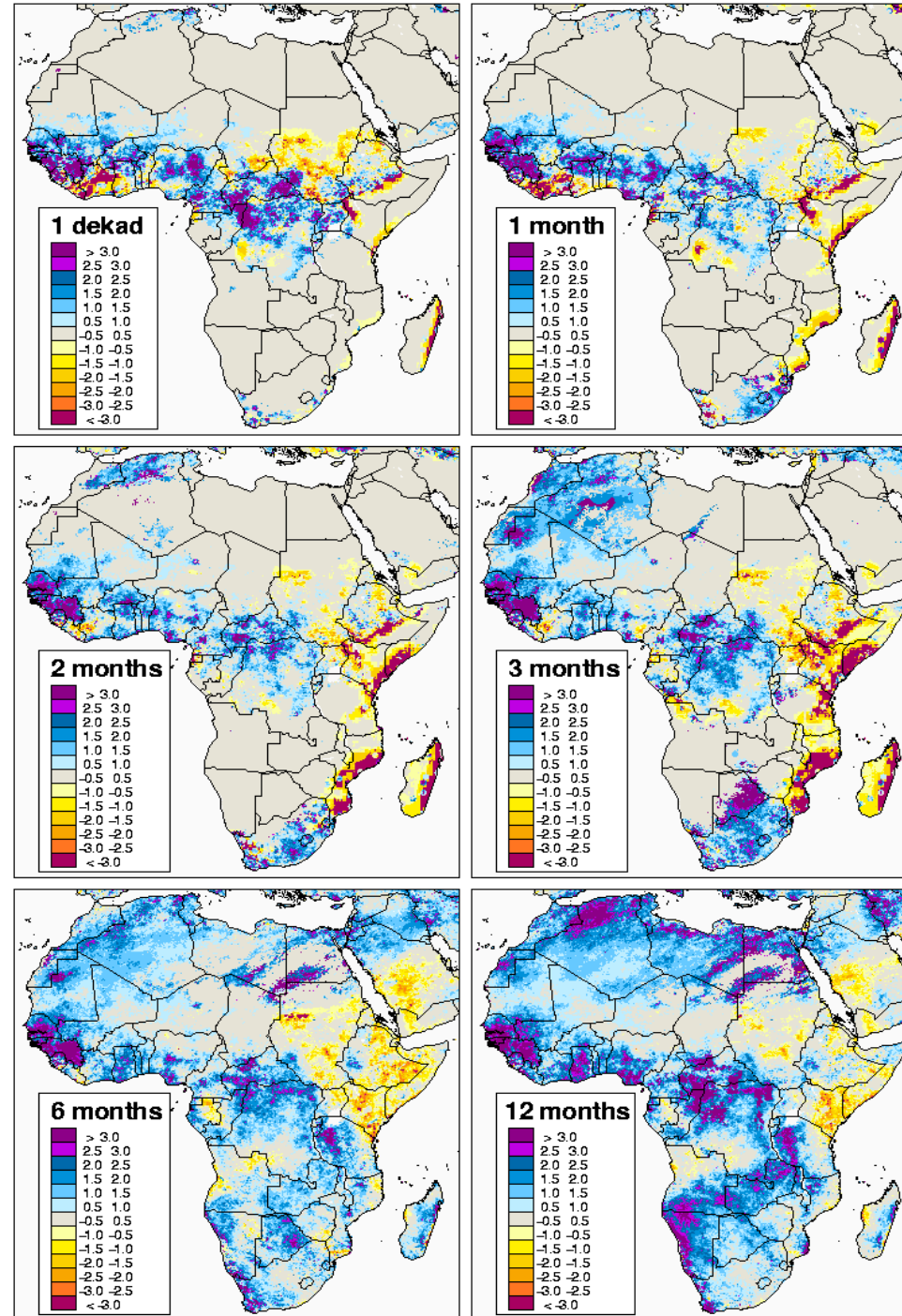
# Soil Water Index (SWI)

The SWI is the percentage of the soil's water holding capacity (WHC).



# Standardized Precipitation Index (SPI)

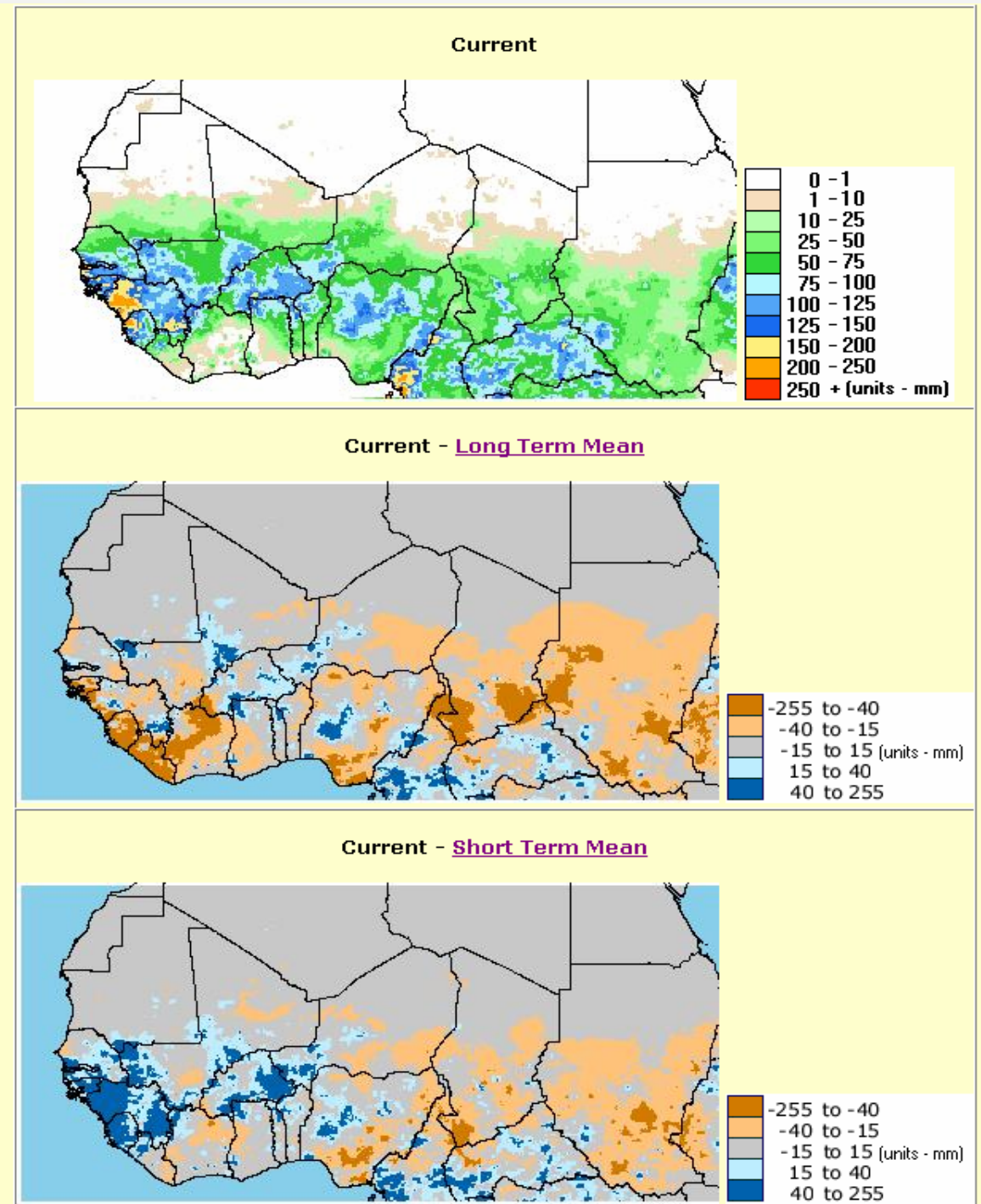
Africa Standardized Precipitation Index (SPI)  
for the indicated accumulation periods  
as of August 20, 2009





# Rainfall Estimate (RFE)

- 8-km spatial resolution
- standard NOAA RFE product
- RFE calculated using:
  - 1) satellite observations from
    - Meteosat,
    - Special Sensor Microwave Imager (SSM/I),
    - Advance Microwave Sounding Unit (AMSU)
  - 2) station rainfall data.



FEWS/NOAA (National Oceanic and  
Atmospheric Administration)  
*Maps and Data*





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[Cyclone Monitoring](#)



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**Meteorological products for the  
Famine Early Warning System Network (FEWS-NET)  
Mesoamerica Famine Early Warning System (MFEWS)  
Asia Flood Network (AFN)**

**Funded by the United States Agency for International Development (USAID)**

NOAA/ National Weather Service  
National Centers for Environmental Prediction  
Climate Prediction Center  
5200 Auth Road  
Camp Springs, Maryland 20746  
Page Author: Climate Prediction Center Internet Team  
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<http://www.cpc.ncep.noaa.gov/products/fews/index.shtml?l=en>





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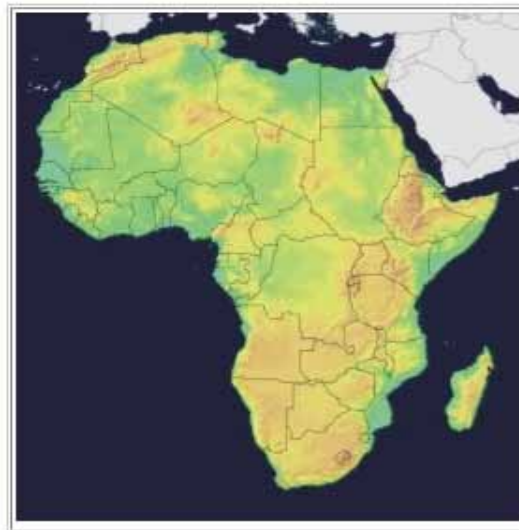
## Famine Early Warning System Network (FEWS-NET)



**USAID**  
FROM THE AMERICAN PEOPLE



Africa meteorological products for the  
Famine Early Warning System Network (FEWS-NET)  
Funded by the United States Agency for International Development (USAID)



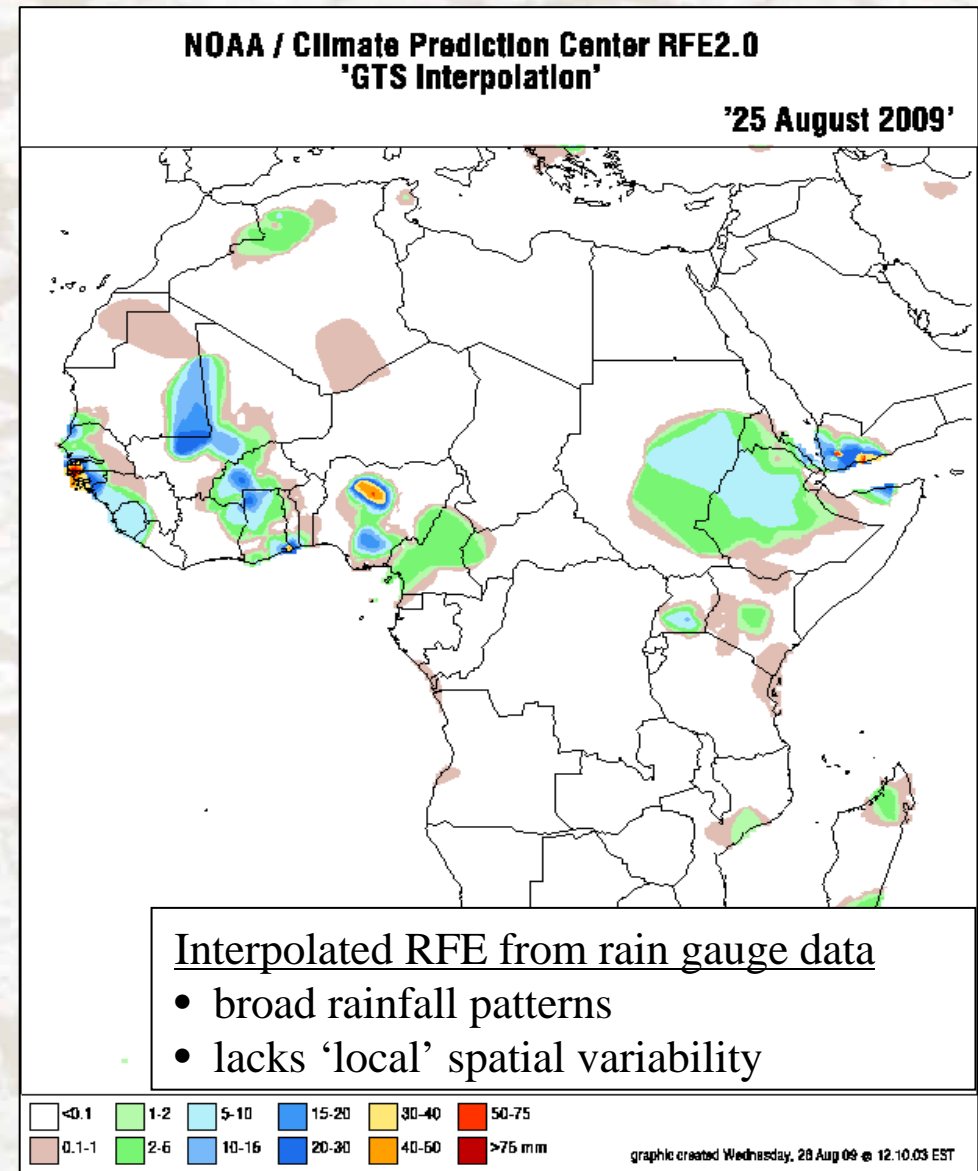
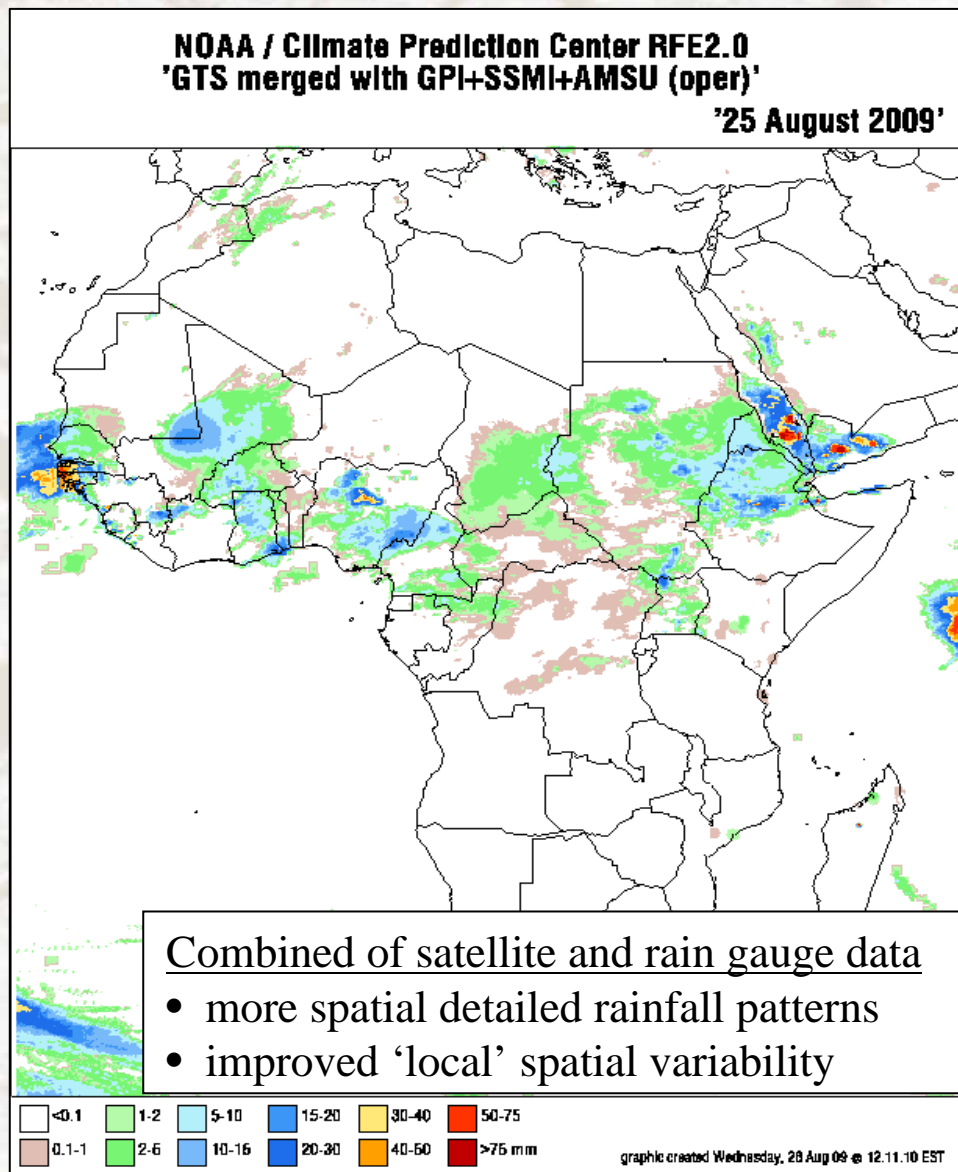
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# Contribution of Remote Sensing to RFE

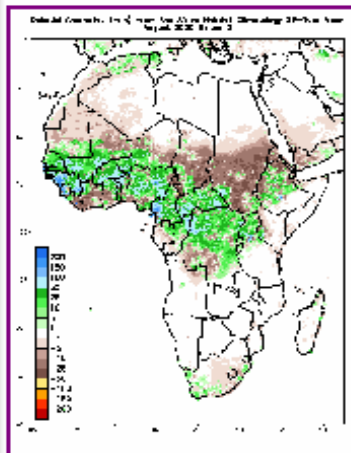


# NOAA / FEW RFE Products

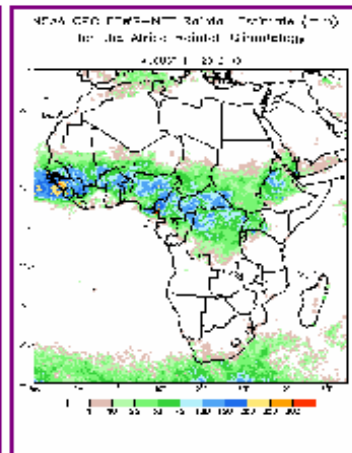
- number of RFE products
  - some are operational, but many experimental variations of operational products
- 0.25 degree spatial resolution
- daily, dekadal, monthly, and seasonal products
- Products available from 2003 to present
- Area-specific products vary
  - continental
  - region-specific (e.g., Sahel)

## Dekadal

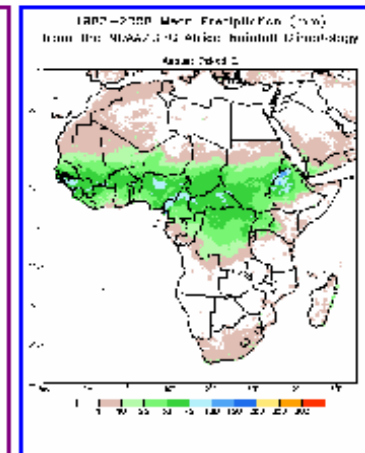
Latest Dekadal 26-year Anomaly (Difference Between Mean 1983-2008 and Current Climatology-Method RFE)



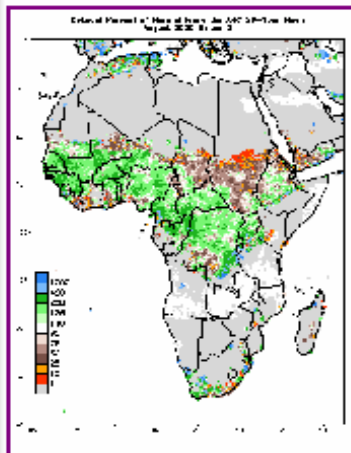
Climatology Method RFE (GPI+GTS)



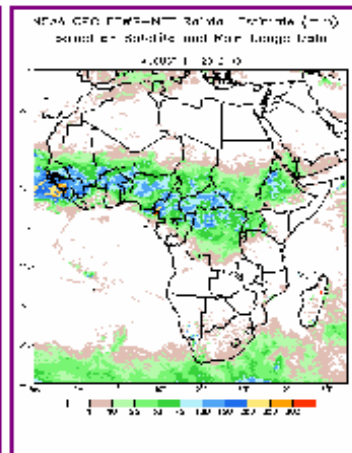
Climatology Method 26 Yr Mean RFE



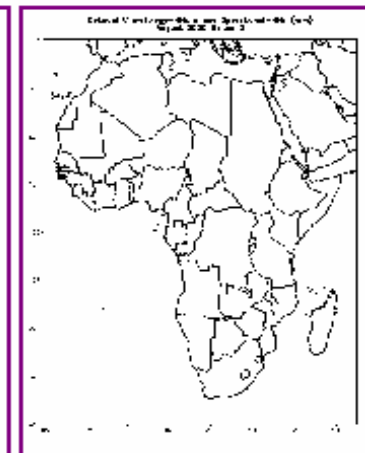
Percentage of Normal (Climatology-Method)



Operational RFE GPI+GTS+SSMI+AMSU



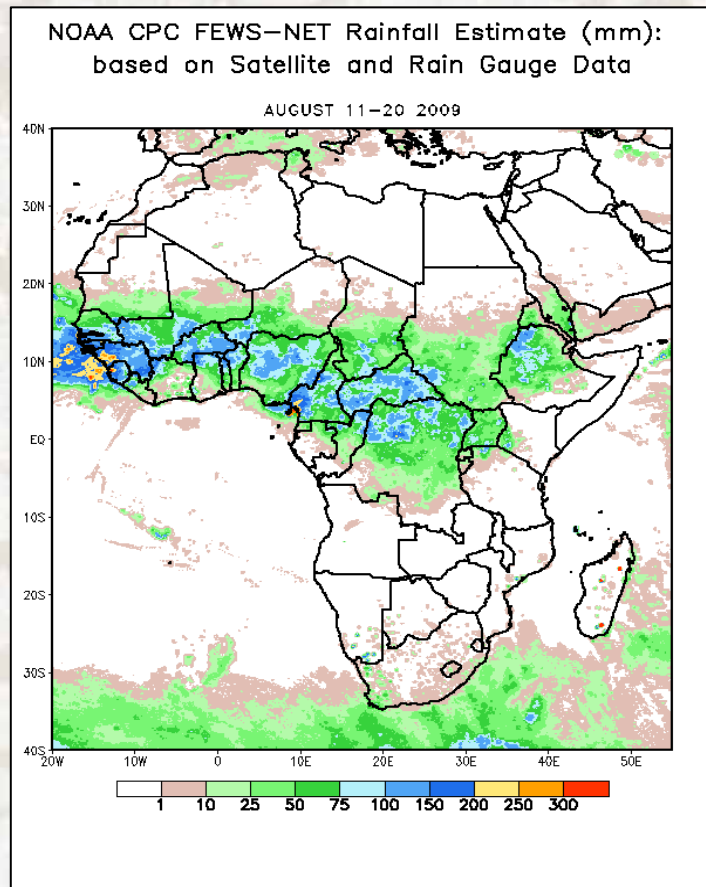
Climatology Minus Operational RFE



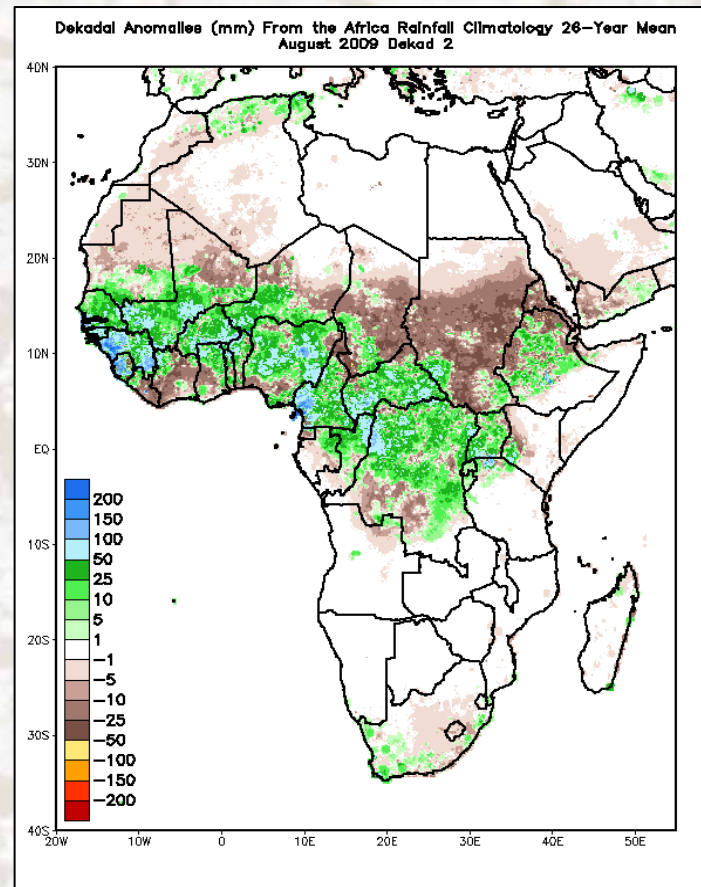


# Africa Rainfall Estimate (RFE) Climatology

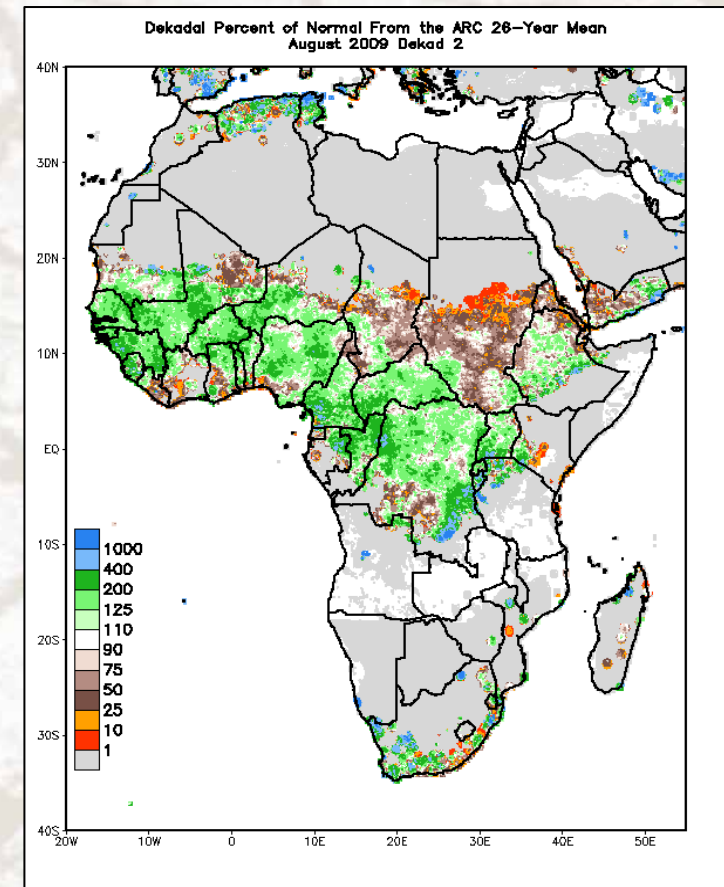
Current RFE (mm)



Difference between Current RFE &  
26-year Mean RFE (mm)



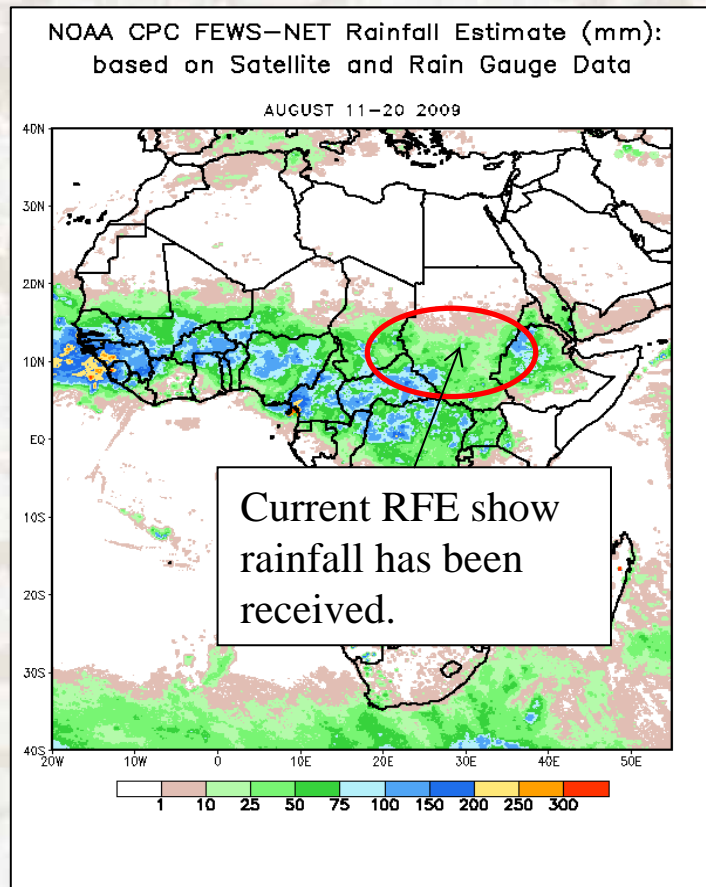
Percent of Historical Mean (%)



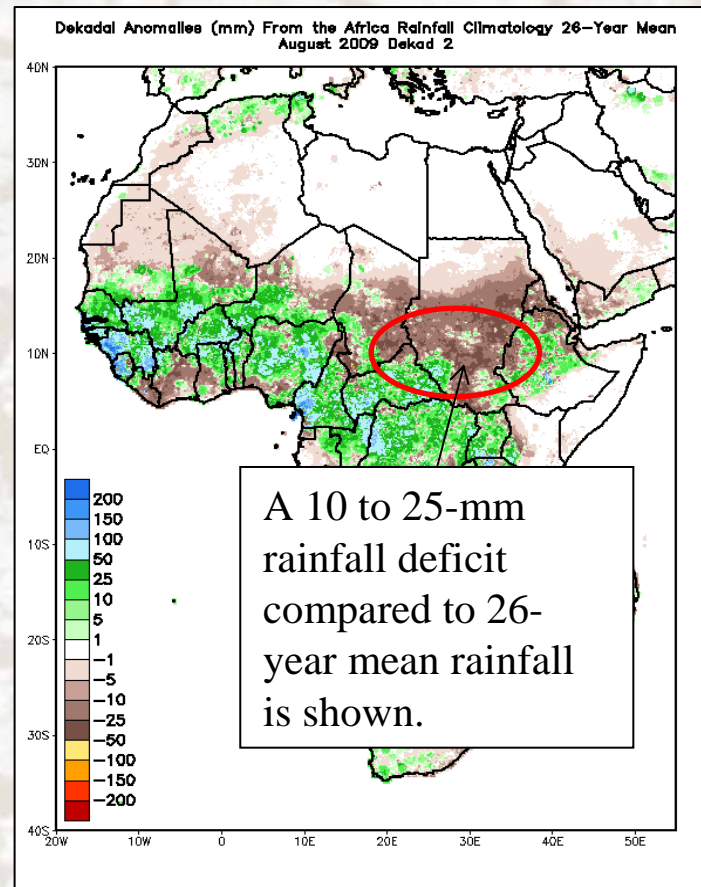
\* Daily, dekadal, and monthly information available.

# Africa Rainfall Estimate (RFE) Climatology

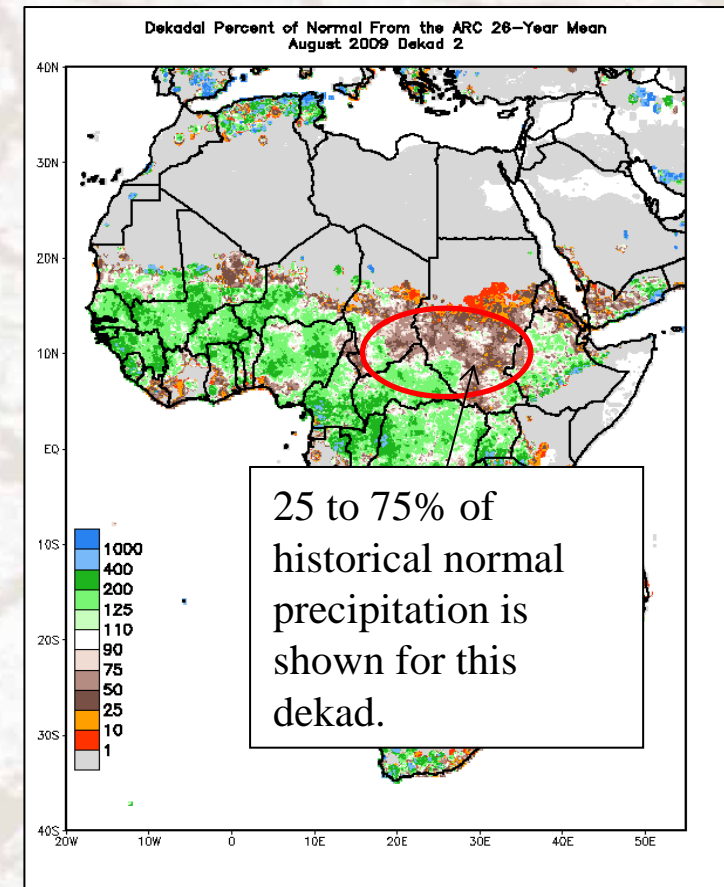
## Current RFE (mm)



## Difference between Current RFE & 26-year Mean RFE (mm)



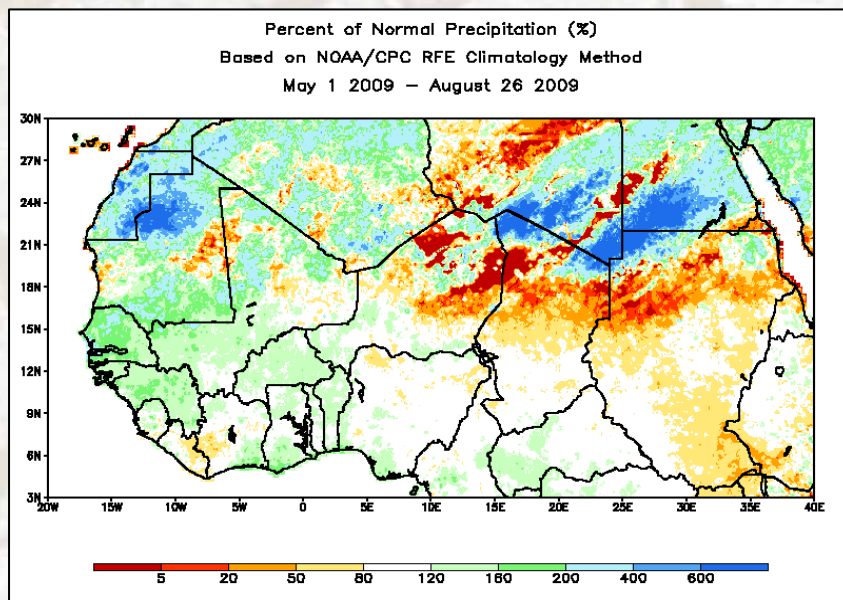
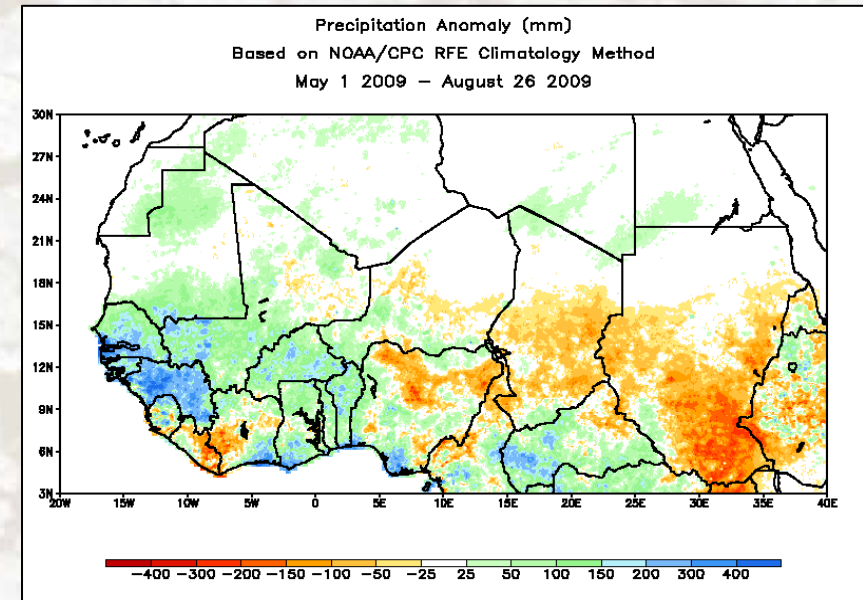
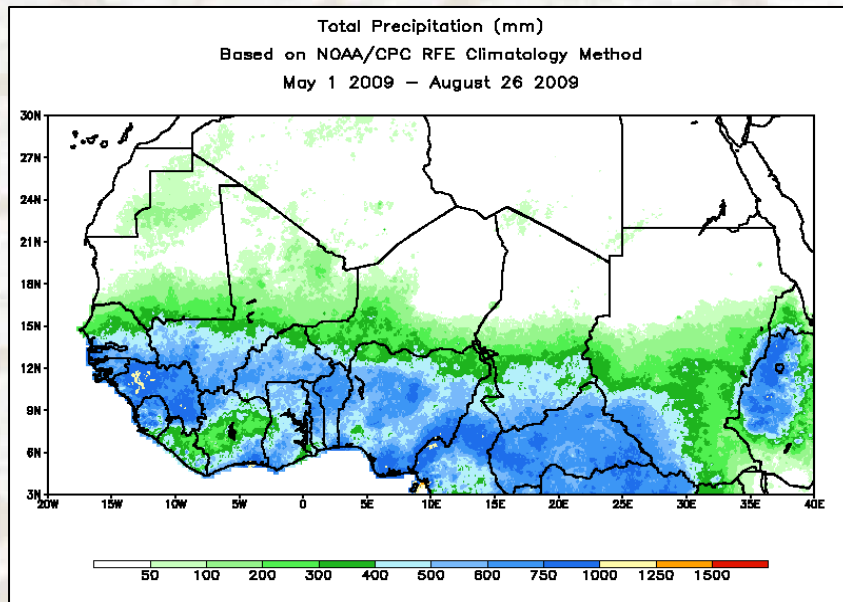
## Percent of Historical Mean (%)



\* Daily, dekadal, and monthly information available.



# Seasonal Rainfall Estimate (RFE) Climatology



- *Season:* May – September
- *Coverage:* Sahel region product  
(no continental-scale maps)
- *Years:* 2004 – 2009

# Advances in Remote Sensing: *The Future for Drought Monitoring*

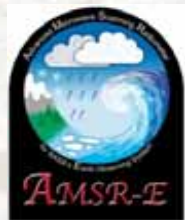




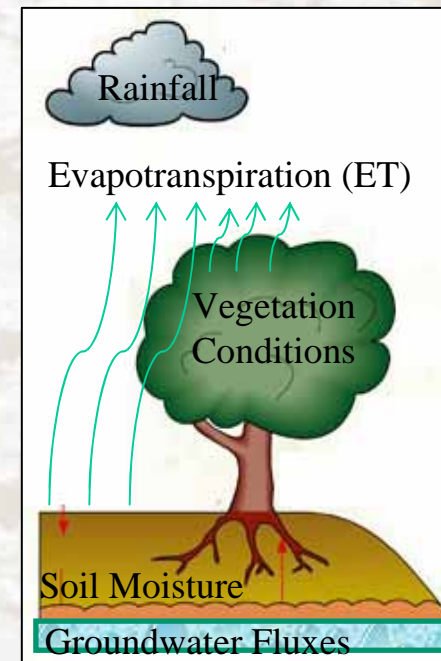
# Progress in Remote Sensing

- Over the past 10 years, many advanced remote sensing instruments have been launched that collect information that can be used monitor different aspects of drought.
- Development of advanced processing and analysis techniques and improved computing capabilities have resulted in new approaches that could be used for drought monitoring.

## *New Remote Sensing Instruments*



## *Remote Sensing-based Estimates of:*



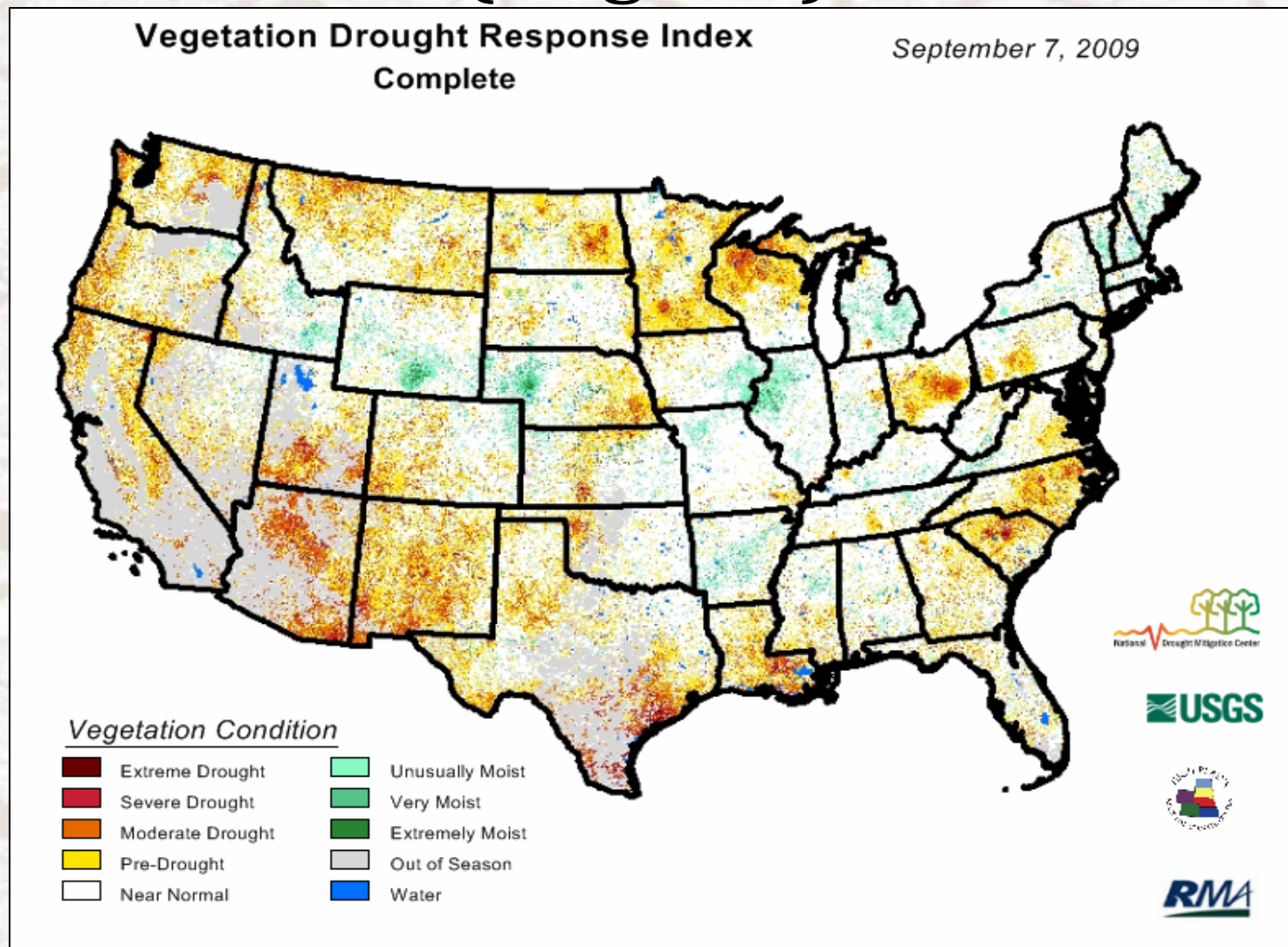
# Vegetation

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# Vegetation Drought Response Index (VegDRI)



[http://www.drought.unl.edu/vegdiri/VegDRI\\_Main.htm](http://www.drought.unl.edu/vegdiri/VegDRI_Main.htm)

# What is VegDRI?

VegDRI is a new ‘hybrid’ drought index that integrates:

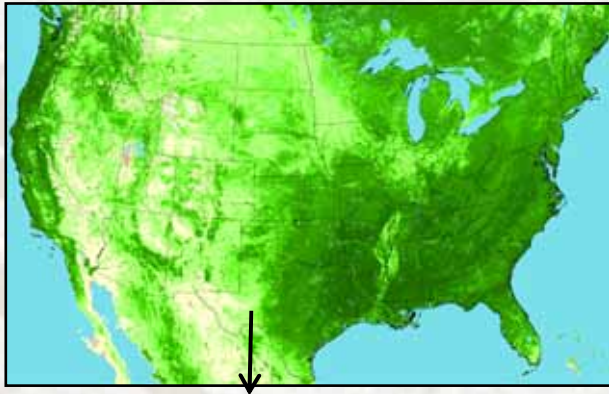
- satellite-based observations of vegetation conditions
- climate-based drought index data
- biophysical characteristics of the environment

to produce 1-km spatial resolution maps that depict ‘*drought-related vegetation stress*’.



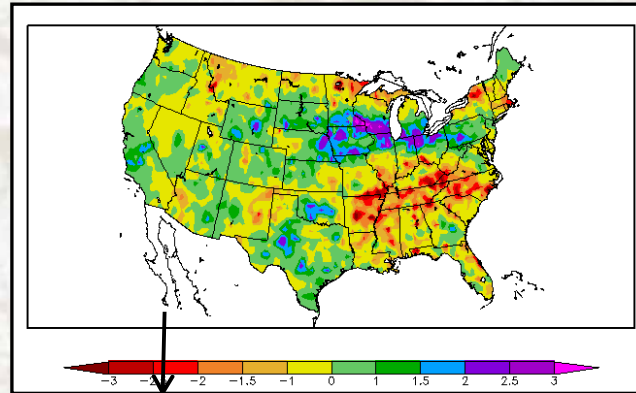
# What is VegDRI?

## *Remote Sensing Component*



Vegetation health information  
- NDVI-based

## *Climate Component*



Measure of dryness

## *Biophysical Component*



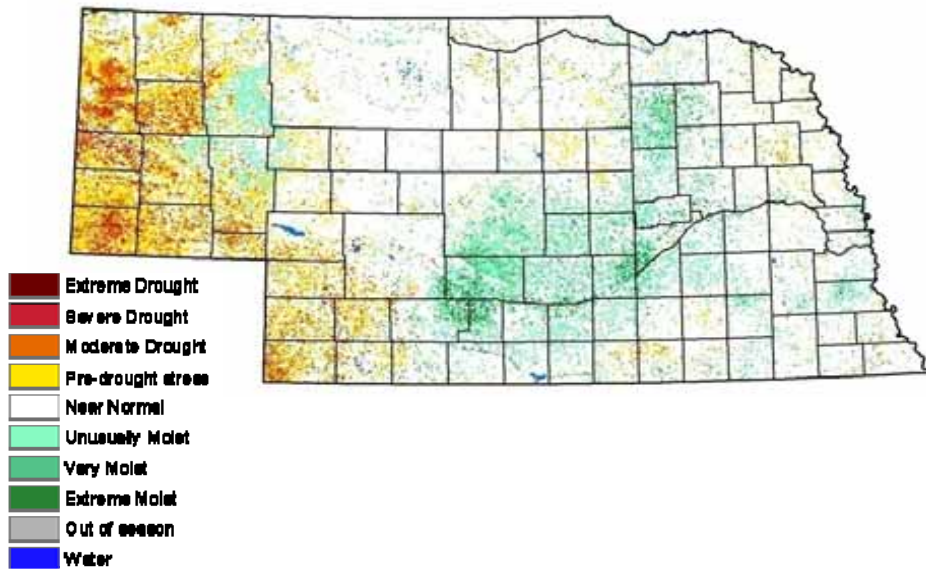
Environmental characteristics  
that influence climate-  
vegetation interactions.

- land use/cover type
- soil characteristics
- elevation
- ecological setting

# VegDRI vs. U.S. Drought Monitor

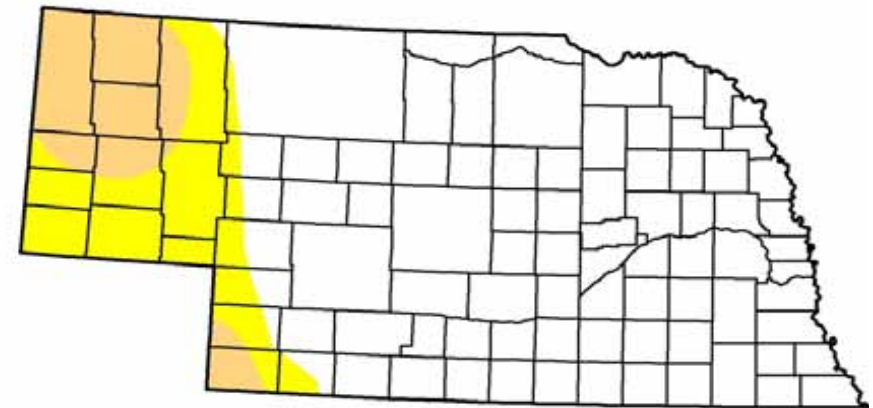
## VegDRI

Nebraska – June 30, 2008



## U.S. Drought Monitor

Nebraska – July 1, 2008



### Intensity:

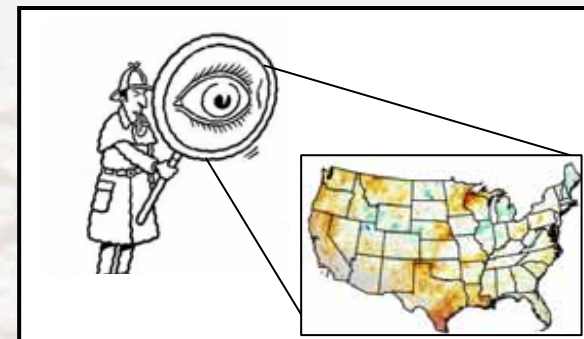


**Goal of VegDRI Tool:** *National-level monitoring* capabilities with *local-scale information* (i.e., county to sub-county level) regarding the level of drought stress on vegetation.



# *VegDRI Evaluation*

**Purpose:** Establish a network of 150+ evaluators across the U.S. that provide periodic feedback regarding the accuracy of the VegDRI maps for their 'local' area.



**Goal:** Collect 'baseline' information about VegDRI's performance and better understand the index's current strengths and weaknesses.

## *Types of feedback:*

- 1) *qualitative:*
  - *visual observations*
  - *photos*
  - *impacts (e.g., cattle sales & feed surplus/deficits)*
  
- 2) *quantitative:*
  - *clip plot data (e.g., biomass)*
  - *rainfall measurements & variations*
  - *production (e.g., 'How yield/forage production compared to the historical average.')*

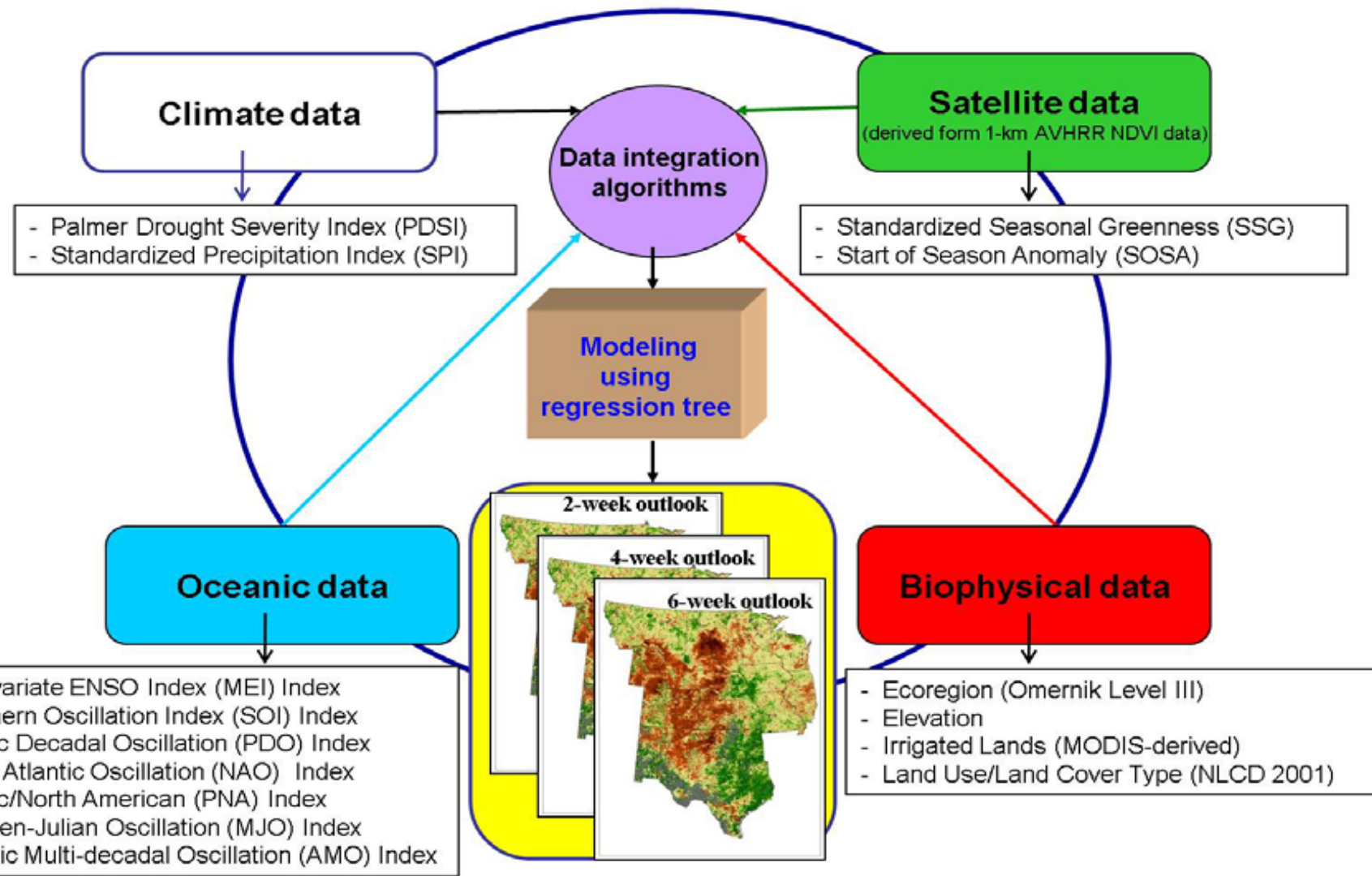
# Vegetation Outlook ( VegOut)

A new experimental tool that provides a series of maps depicting future outlooks of general vegetation conditions (seasonal greenness) based on an analysis of:

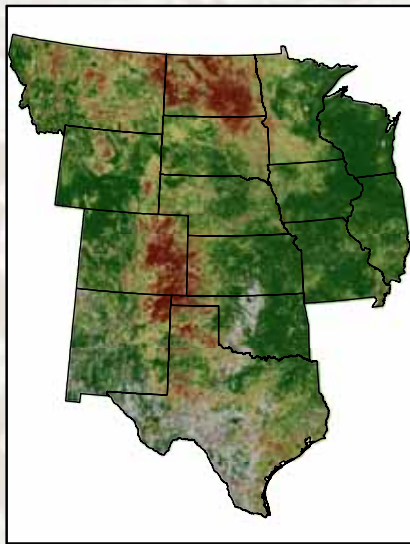
- 1) climate-based drought indices
- 2) satellite-based observations of vegetation
- 3) general biophysical characteristics of the environment
- 4) oceanic indicators.



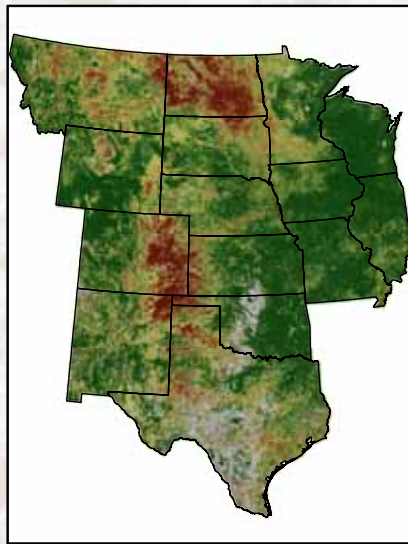
# Overview of the Vegetation Outlook (VegOut) Model



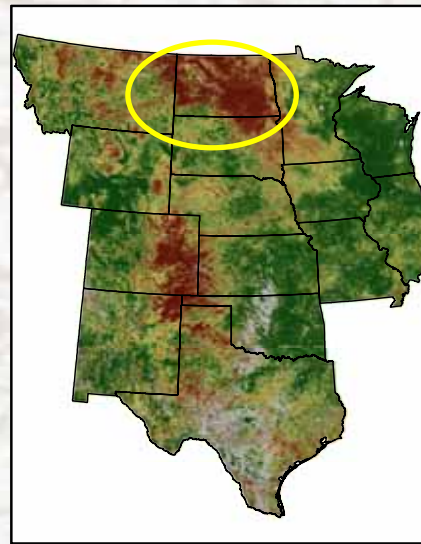
# VegOut Maps for the Central U.S.



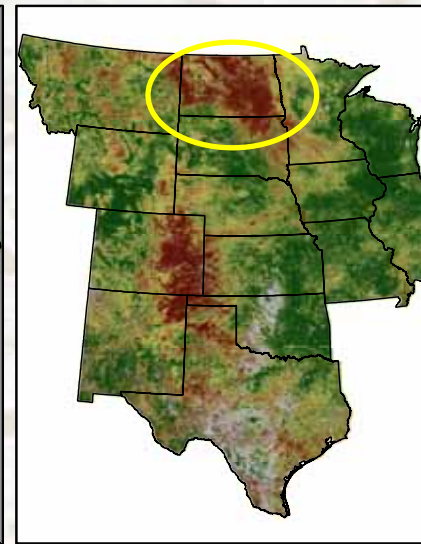
(a) Observed SSG for July 28, 2008



(b) 2-week SSG prediction for August 11

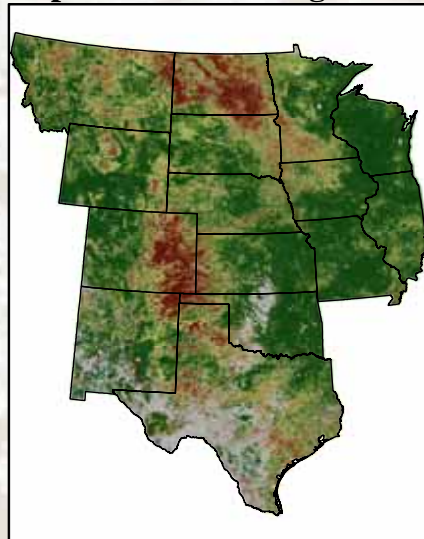
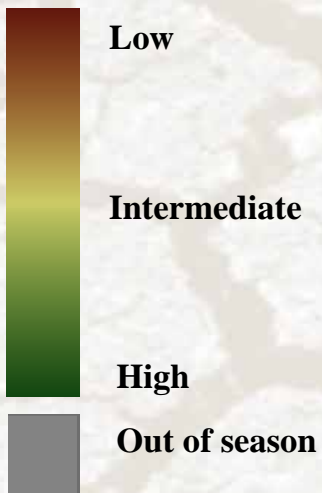


(c) 4-week SSG prediction for August 25

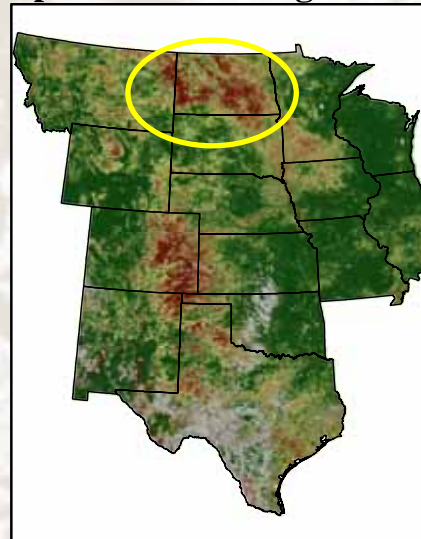


(d) 6-week SSG prediction for September 8

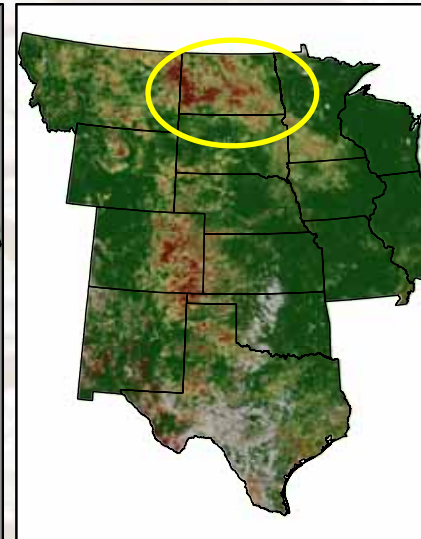
## Standardized Seasonal Greenness (SSG)



(e) Observed SSG for August 11



(f) Observed SSG for August 25



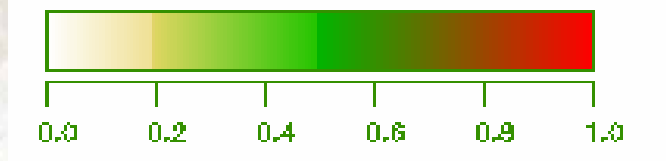
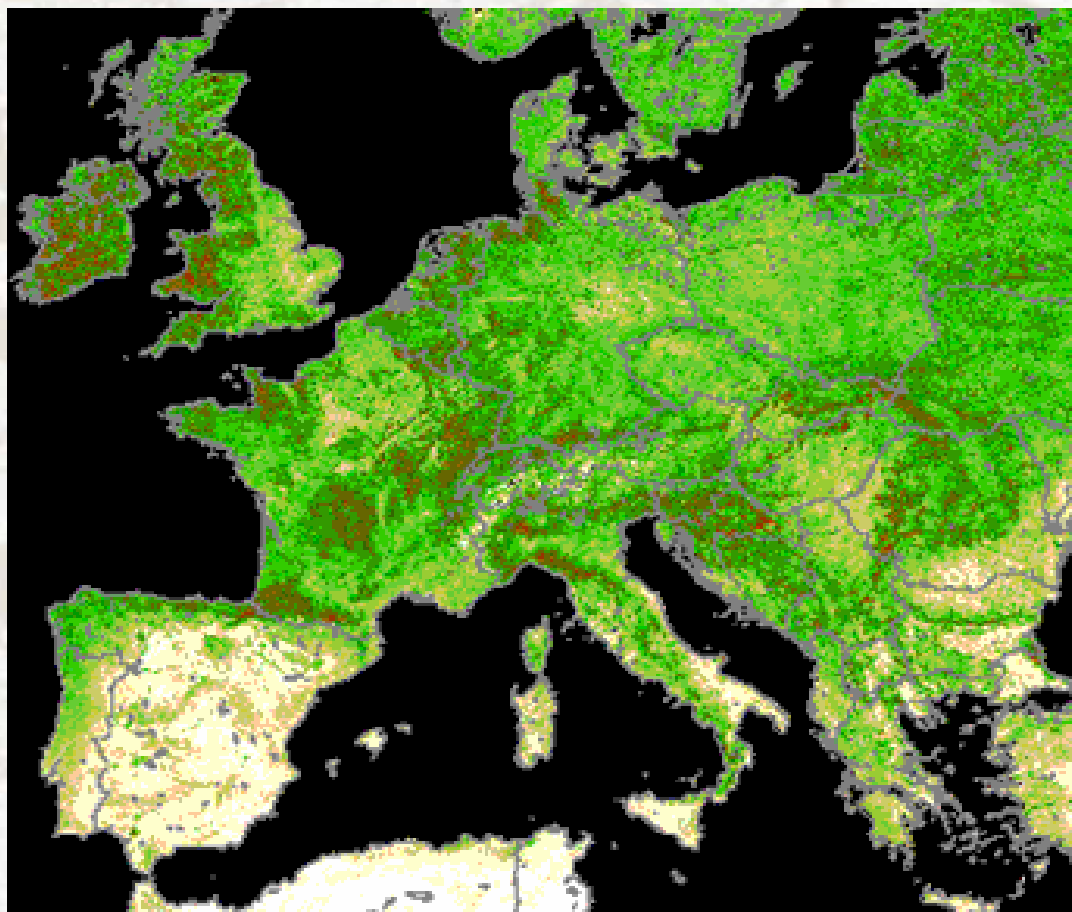
(g) Observed SSG for September 8

## Results:

- Slight under-estimation of greenness in areas of low greenness.
- Slightly lower predictive accuracy with longer outlook period.



# Fraction of Photosynthetically Active Radiation (FPAR)



-**FPAR** is the fraction of solar radiation absorbed by vegetation and is:

- 1) indicator of the presence and state of vegetation cover
- 2) quantitative estimate related to productivity.

-Product of the European Drought Observatory (EDO)

-2- & 8-km spatial resolution

-10-day up-date cycle

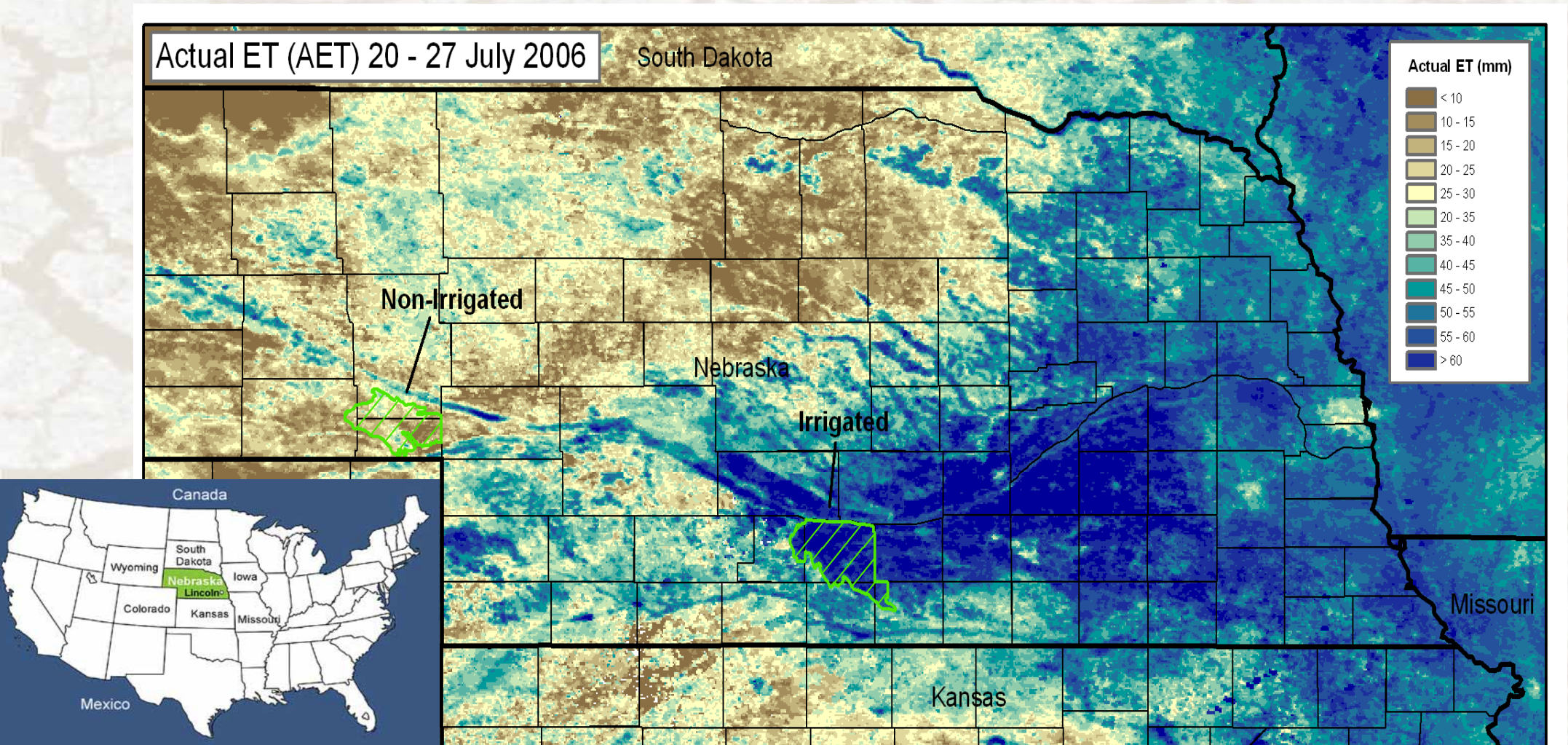
# Evapotranspiration (ET)

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# Actual Evapotranspiration (AET)

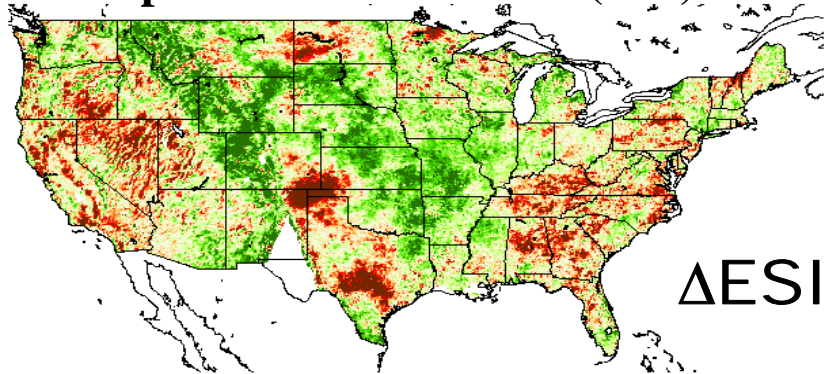


*Courtesy: Senay and Budde (2008)*

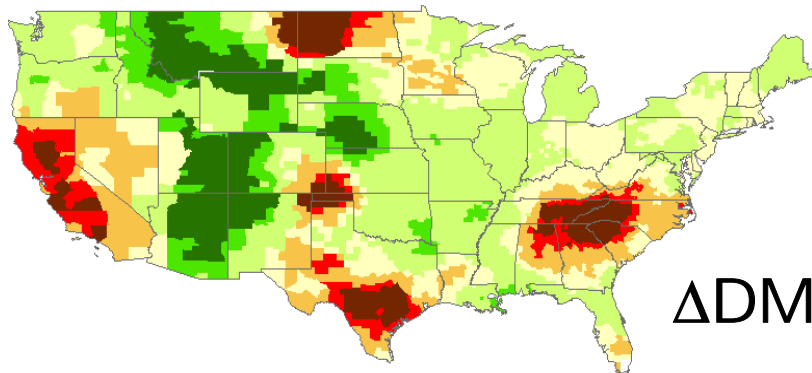
Actual ET map (1-km resolution) derived from remotely sensed thermal data and an energy surface balance model.

# Evaporative Stress Index (ESI)

Evaporative Stress Index (ESI)



U.S. Drought Monitor (USDM)



**Drier**  **Wetter**  
**SEASONAL ANOMALIES (9-year record)**  
**April – September 2008**

Courtesy: M. Anderson USDA ARS (2008)

**ESI** depicts ‘transpiration’ fluxes from vegetation and ‘evaporative’ fluxes from non-vegetated surfaces (e.g., soils).

- developed by U.S. Department of Agriculture’s (USDA) Agricultural Research Division (ARS)
- use thermal observations from satellite in surface energy balance model
- Can be applied to data from multiple sensors:
  - Spatial resolution of ESI can range from 30-m to 8-km
  - Updated hourly, daily, or every 1-2 weeks.



# Soil Moisture & Groundwater

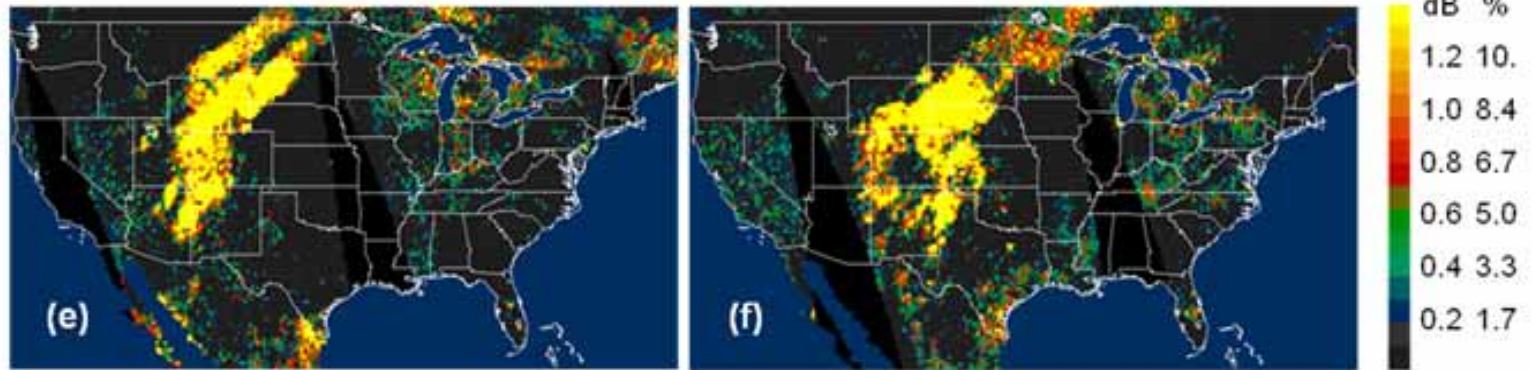
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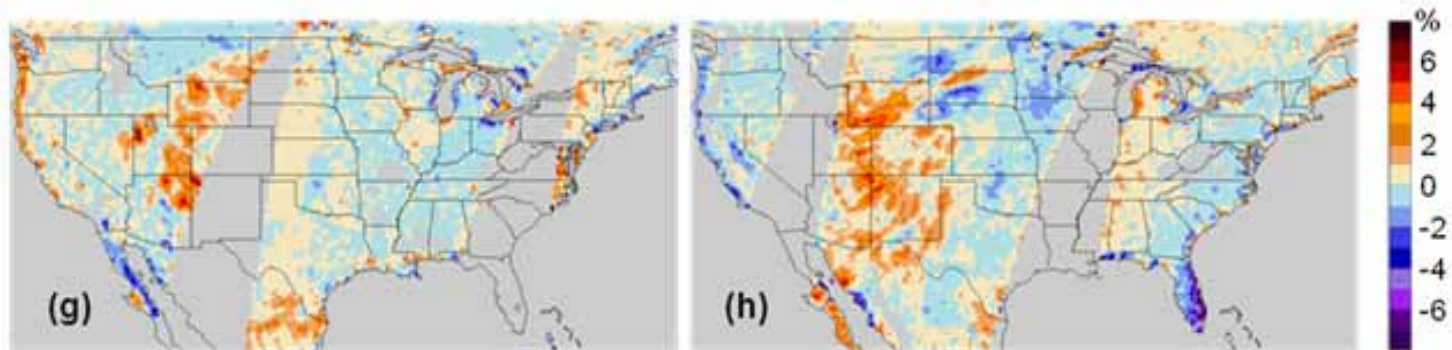
# Soil Moisture

New NASA satellite-based microwave sensors (QSCAT and AMSR) provide data to estimate shallow soil moisture changes (upper 5 cm).

**QSCAT  
Soil Moisture  
Change  
(upper 5 cm)**



**AMSR  
Soil Moisture  
Change  
(surface)**



*Courtesy: Nghiem et al., (2008)*

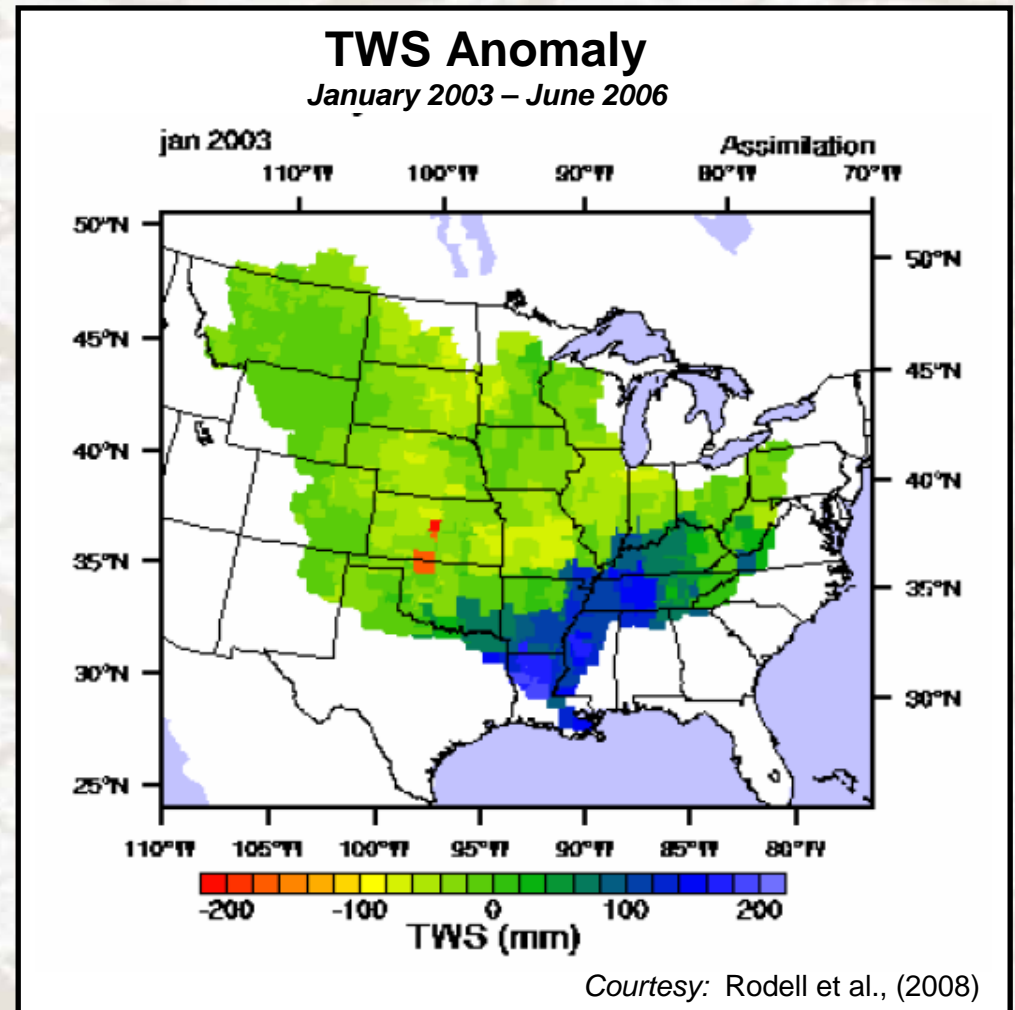


# Terrestrial Water Storage (TWS)

## Terrestrial Water Storage (TWS)

represents:

- 1) soil moisture
  - 2) groundwater
  - 3) snow water equivalent
- Calculated from gravity data collected by the new GRACE (Gravity Recovery and Climate Experiment) instrument and Land Data Assimilation System (LDAS).
  - Coarse spatial resolution (~4 degree)
  - Near real-time production



**Thank you for your attention.**



**For further information, please contact:**

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National Drought Mitigation Center

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