Evapotranspiration for Drought Monitoring and Early Warning: FEWS NET Application

Gabriel Senay
USGS

2015 International Workshop on Evapotranspiration Mapping for Water Security
Sponsored by NASA and the World Bank
September 15-17 , 2015
The World Bank 1818 H St NW, Washington, DC

Team and Contributors

- Jim Verdin
- Jim Rowland
- Mike Budde
- Stefanie Bohms
- MacKenzie Friedrichs
- Manohar Velpuri
- Ramesh Singh
- Harikishan Jayanthi

USGS

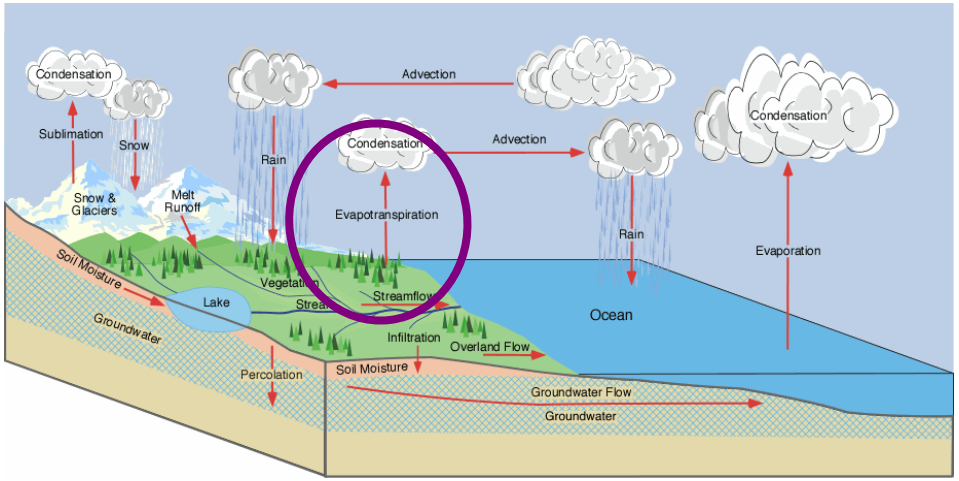
Outline

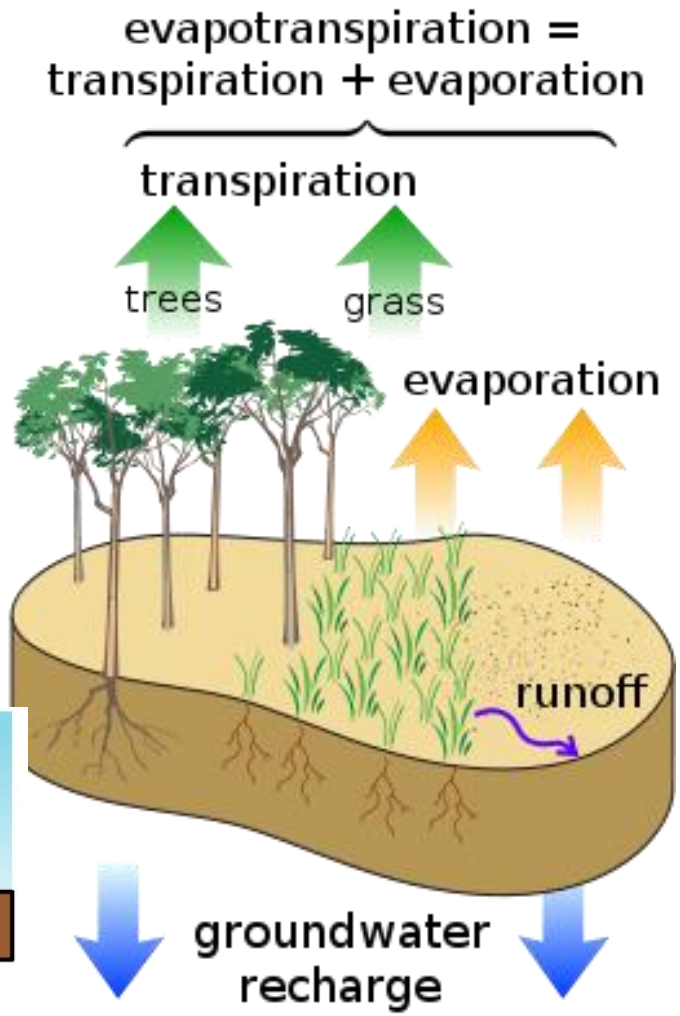
- Summary
- Background and justification for remote sensing ET
- ET Products (drought monitoring and early warning)
  - Global and Regional
- Crop Insurance Applications
- Conclusions

Summary

- Satellite-based ET is being estimated operationally using Land Surface Temperature (LST) as the main driver.
- Applications for drought monitoring is reliable as is.
- Applications for water balance studies require calibration with local observations for bias removal.

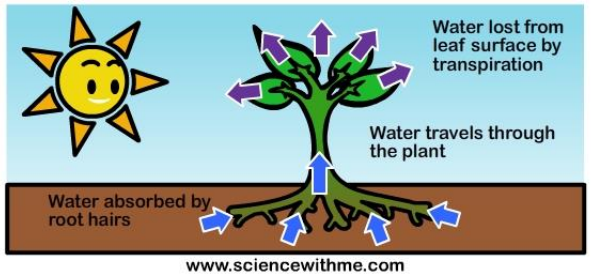
Hydrologic cycle

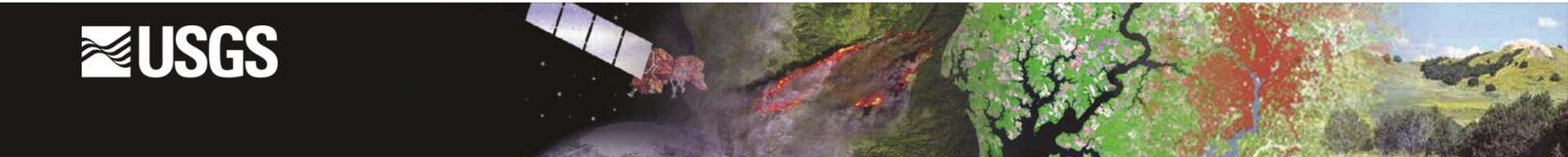




Challenge with ET:

1) Gaseous state
2) Invisible
3) Only indirect measurement





Why ET?

- It is a **RESPONSE** variable as opposed to precipitation (driver)
- It reflects the integrated effects of Energy/Aerodynamics, Soil Moisture, Vegetation and Environmental Stress

Potential

Energy | Wind/RH

Limitations

Moisture | Vegetation | Env. Stress

USGS

ET is Directly Related to and Useful for:

- Crop production monitoring
- Irrigation water use and groundwater withdrawal (water budget)
- Carbon budget
- Land cover change monitoring

Remote Sensing ET Research and Application Funded by:

USAID FEWS NET

WaterSMART/USGS Water Census

Role of Remote Sensing

- Land Surface Temperature (LST) from thermal imagery
  - Landsat (~100m)
  - MODIS (1km)
  - AVHRR (1km)
  - GOES (10km)

- Precipitation Estimate
  - NOAA NEXRAD (5km)
  - METEOSAT RFE (10km)
  - NASA TRMM (25 km), etc

Two Principles for ET Estimation…

- **Water Balance**
  - **driven by precipitation accounting**
- **Energy Balance**
  - **driven by Land Surface Temperature (LST)**

Several Approaches…

- Soil Moisture Modeling
- Land Surface Models such as Noah, SWAT, VIC, VegET…
- Vegetation Index based
  - NDVI/LAI-based: MOD16, P-M, P-T
- Mixed Approach
  - NDVI-LST (Trapezoid, Triangle…)
- Surface Energy Balance
  - SEBAL/METRIC, SEBS, Two-Source, ALEXI, S-SEBI, SSEBop…

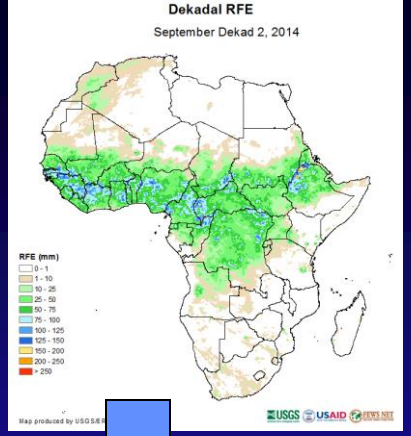
USGS

Which model(s) to use…

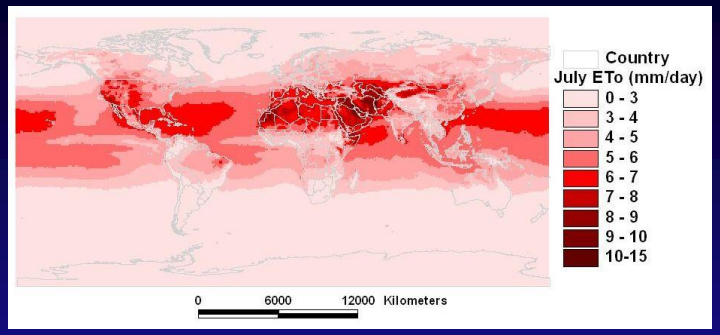
All models are wrong but some are useful

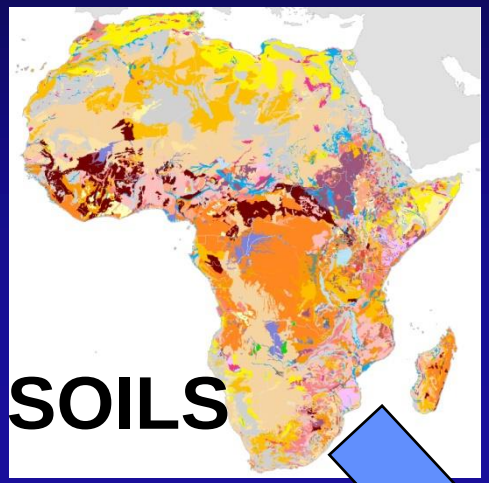
(George E. P. Box, 1976)

PRECIPITATION



Reference ETo





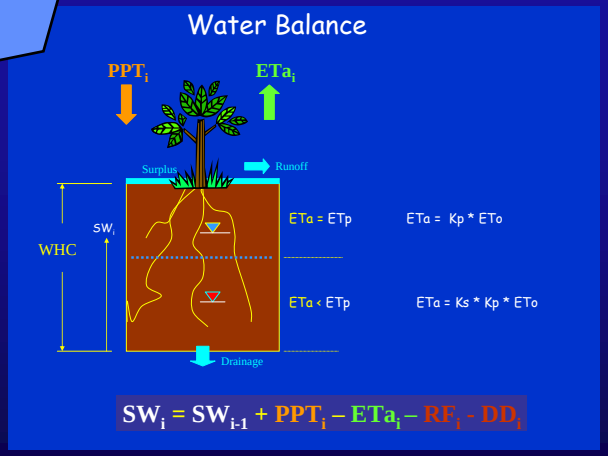
VegET

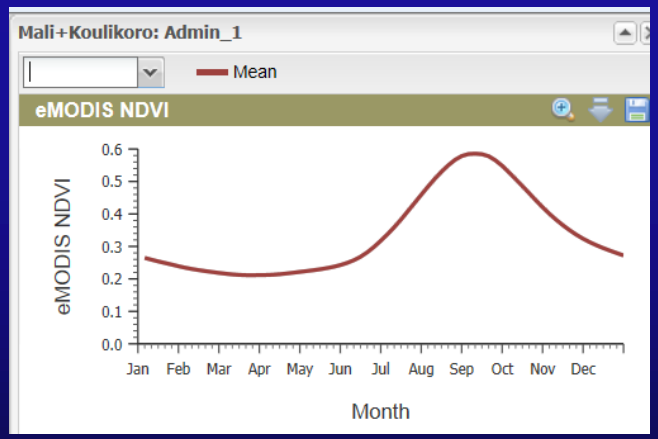
$$ETa = Ks * Kcp * ETo$$

Soil Stress Coefficient

LSP Water-Use Coefficient

Water Balance Model





Land Surface Phenology (LSP)

USGS

Water Balance Limitations

- Requires:
  - rainfall data
  - characterization of vegetation water-use patterns
  - information on soils

- Difficult to estimate:
  - irrigation applications
  - sub-surface extraction by deep rooted plants and wetland ET
  - The impact of pest and diseases on ET

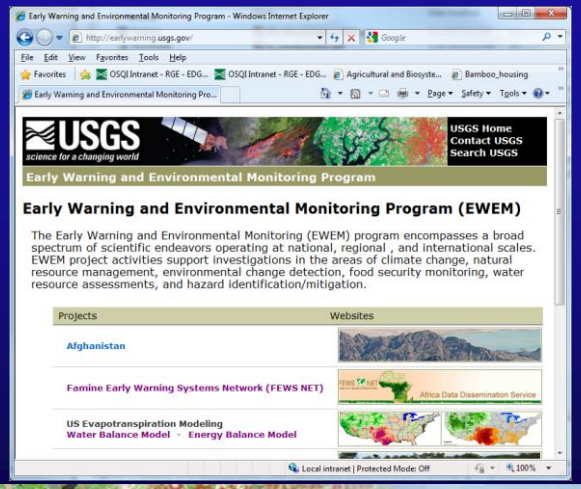
Energy Balance Approach for ET:

Accounts for water, agronomic and environmental stresses

USGS WaterSMART and FEWS NET use the SSEBop (Operational Simplified Surface Energy Balance) approach for:

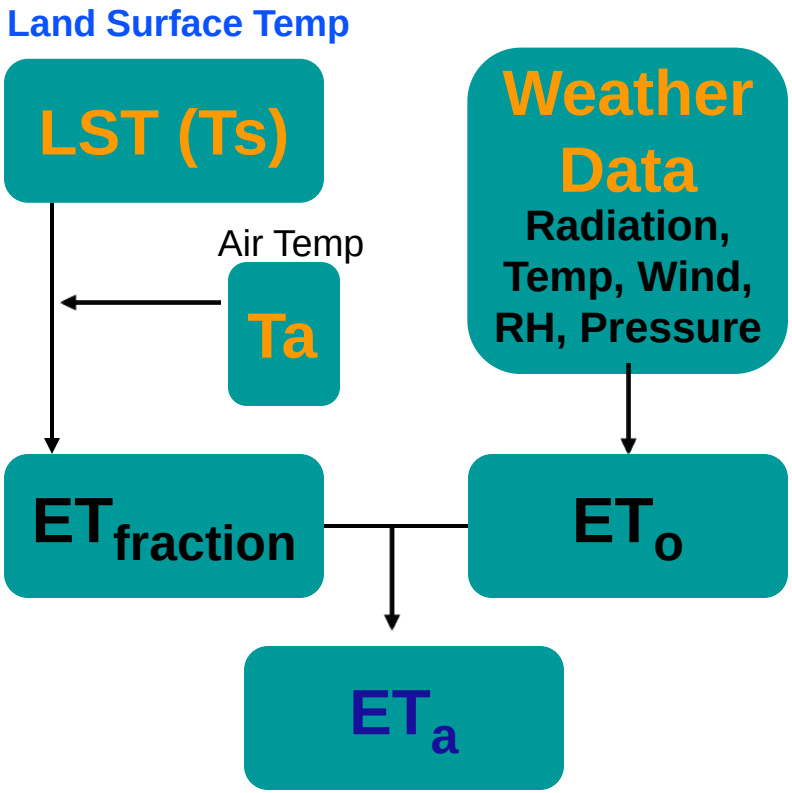
1) Water Use and Availability Assessment

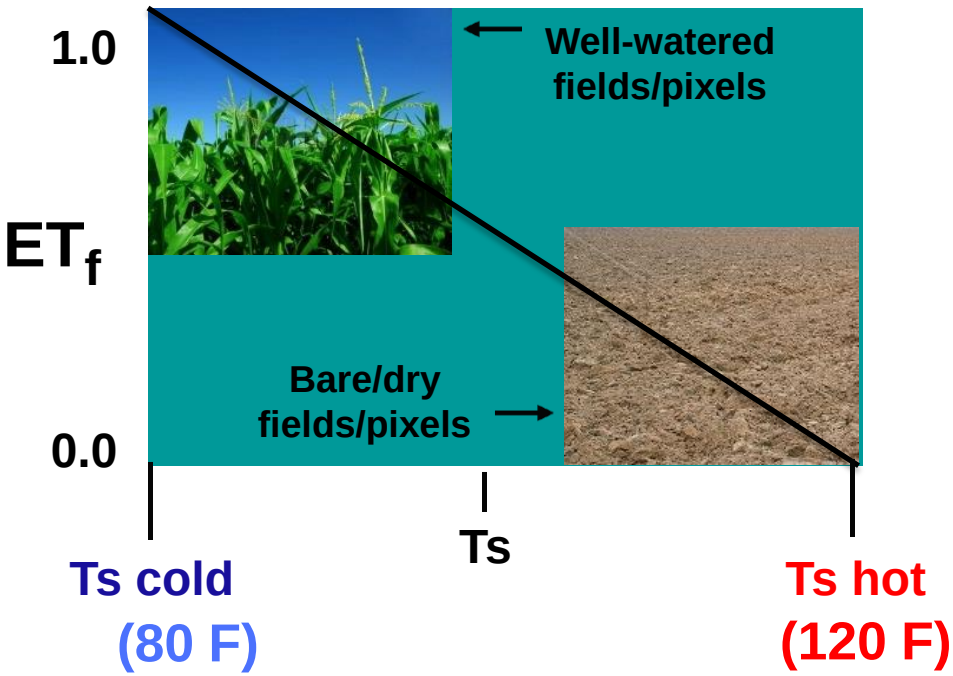
2) Drought Monitoring & Early Warning



USGS

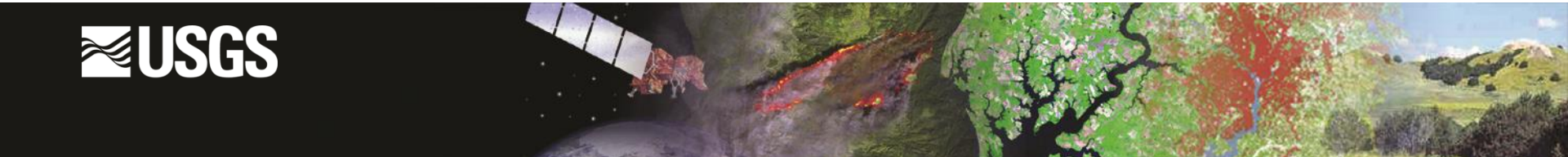
Operational Simplified Surface Energy Balance (SSEBop) Modeling Approach





Adapted the "hot" and "cold" pixel concept from SEBAL (Bastiaanssen et al., 1998) and METRIC (Allen et al., 2007) to calculate ET fraction and combine it with ETo.

SSEB: Senay, et al., 2007 sensors; 2011 AWM; SSEBop: 2013 JAWRA.

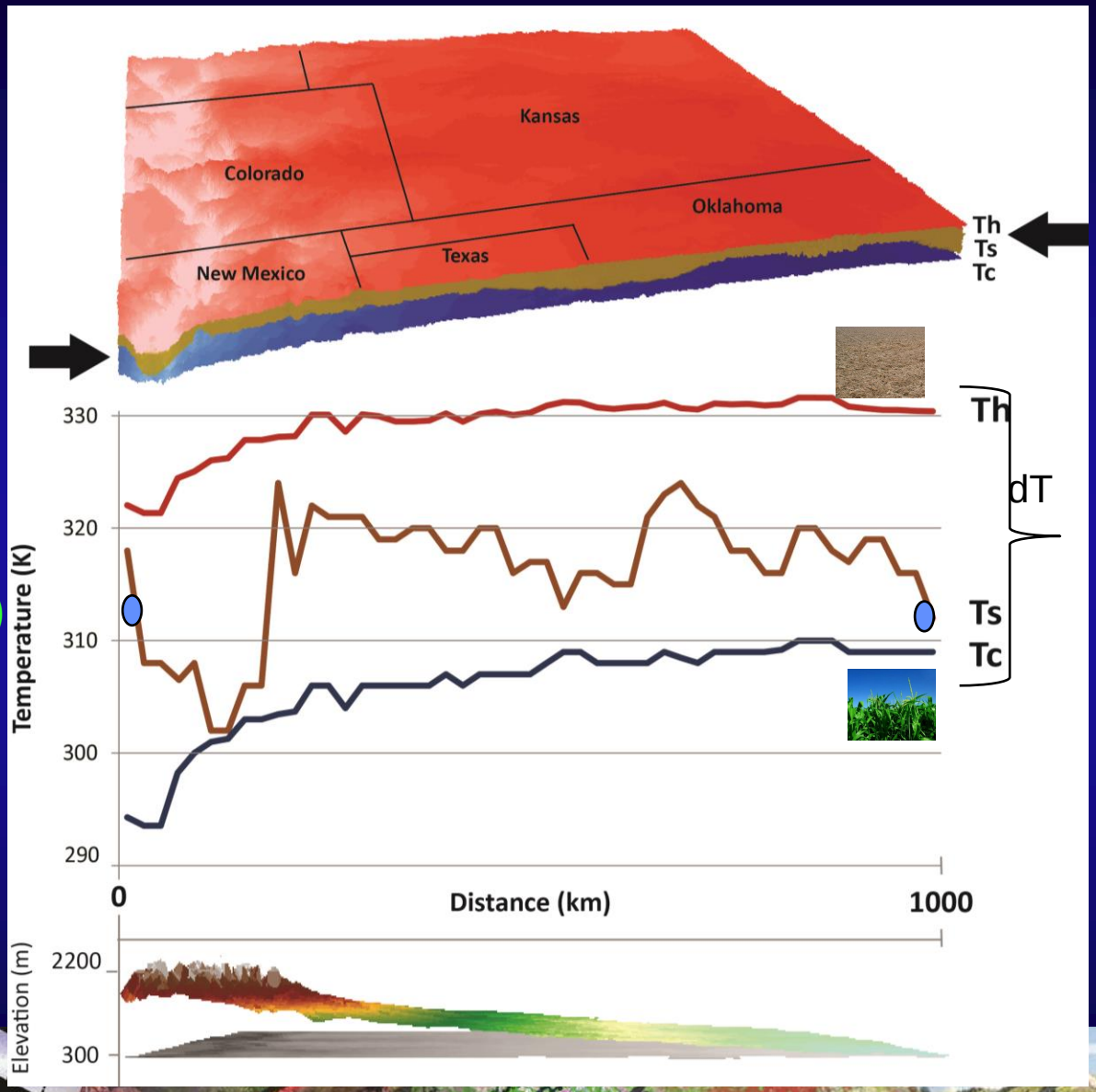


Pre-defined hot/dry and cold/wet limits are KEY!

Jul 4, 2012

Transect:
Ts = MODIS LST
Tc= Cold boundary (c.Ta_max)
Th = Tc + dT

310 k = 99 F
330 k = 135 F



USGS

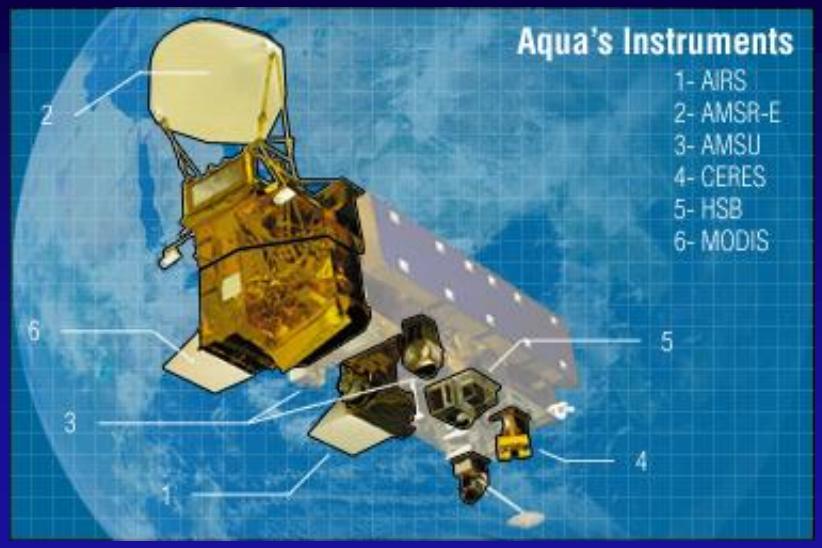
Source of LST and reference ETo

- Land Surface Temperature (LST) from thermal imagery
  - Current implementation with SSEBop
    - Landsat (~100m)
    - MODIS (1km)
- Air Temp: Daymet, TopoWx, PRISM, Worldclim
- ETo: model assimilated global weather datasets such as GDAS and NLDAS or station-based P-M ETo fields.

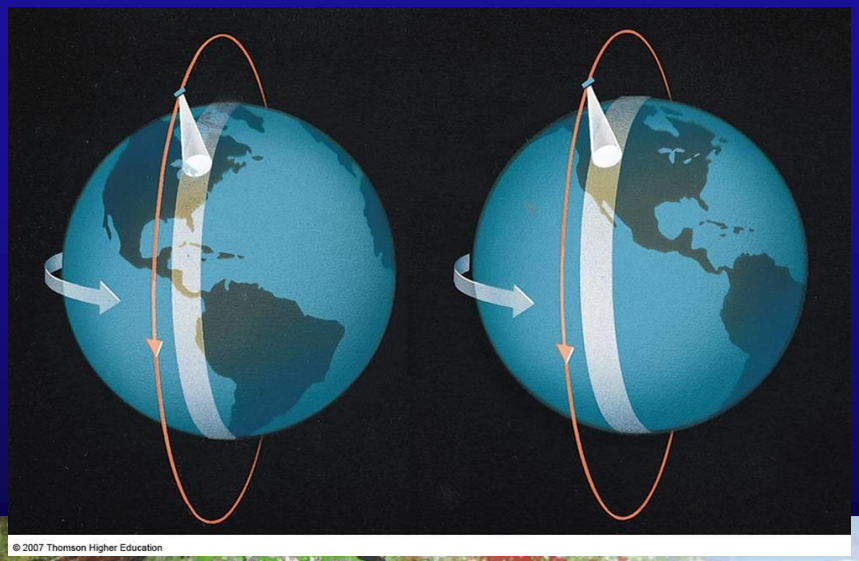
USGS

Images from a polar orbiting satellite

Satellite: Aqua (EOS PM-1)
Sensors: MODIS, and 5 others
Altitude: 705 km
Repeat: daily at 1:30 pm (Equator)
Period: 99 minutes

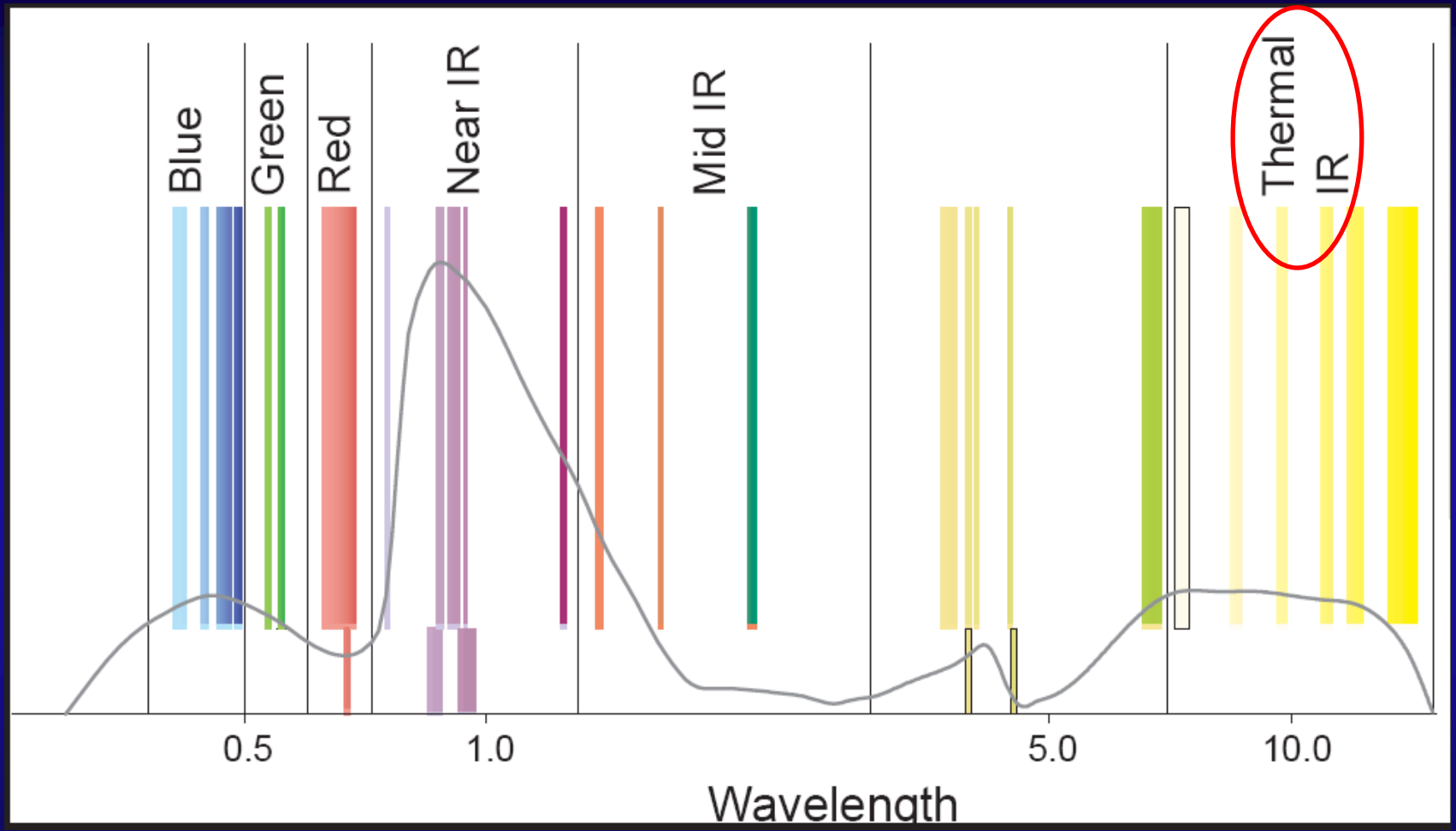


MODIS: Moderate-resolution Imaging Spectroradiometer



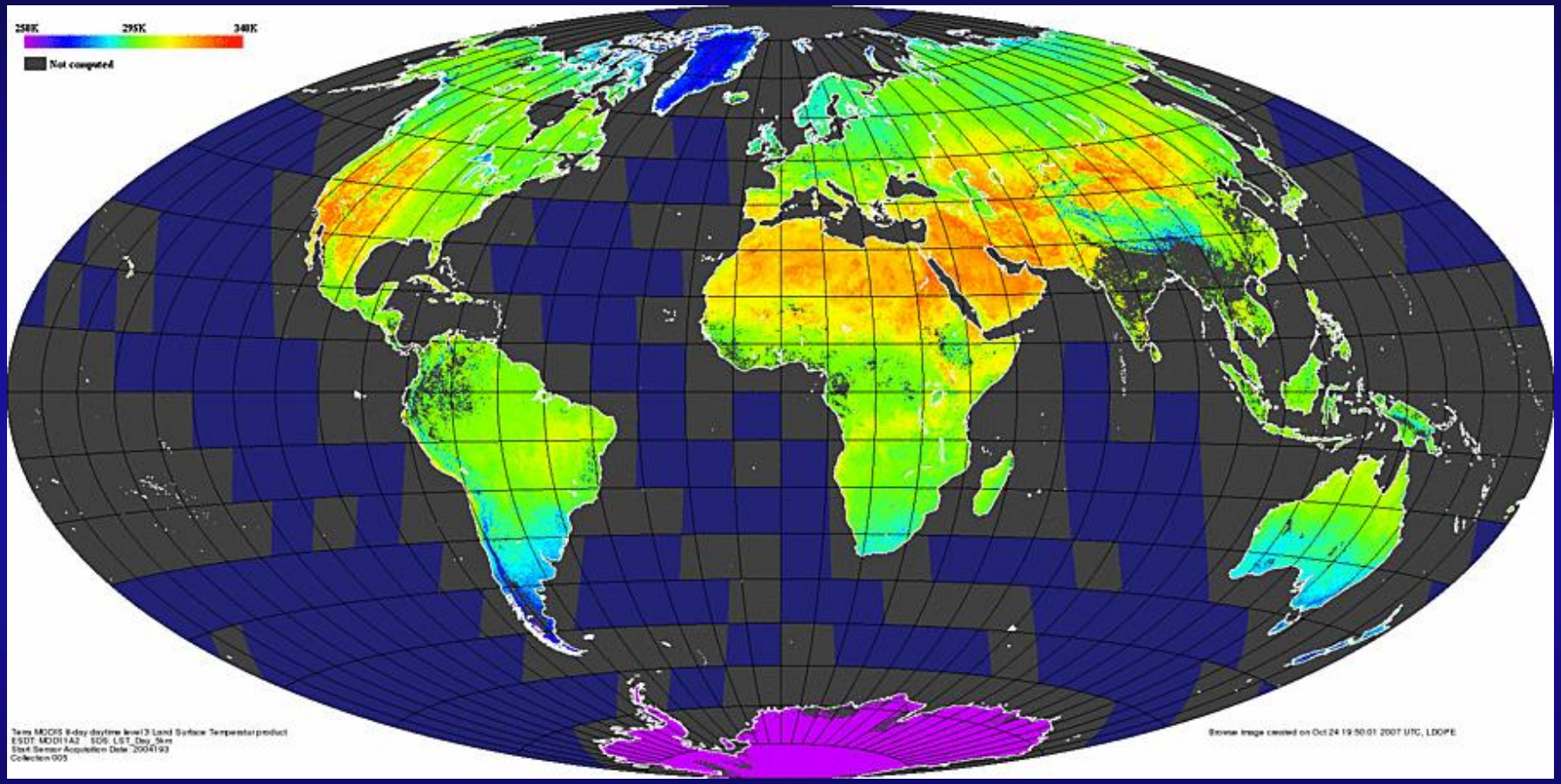
USGS

MODIS Spectral Bands (36)



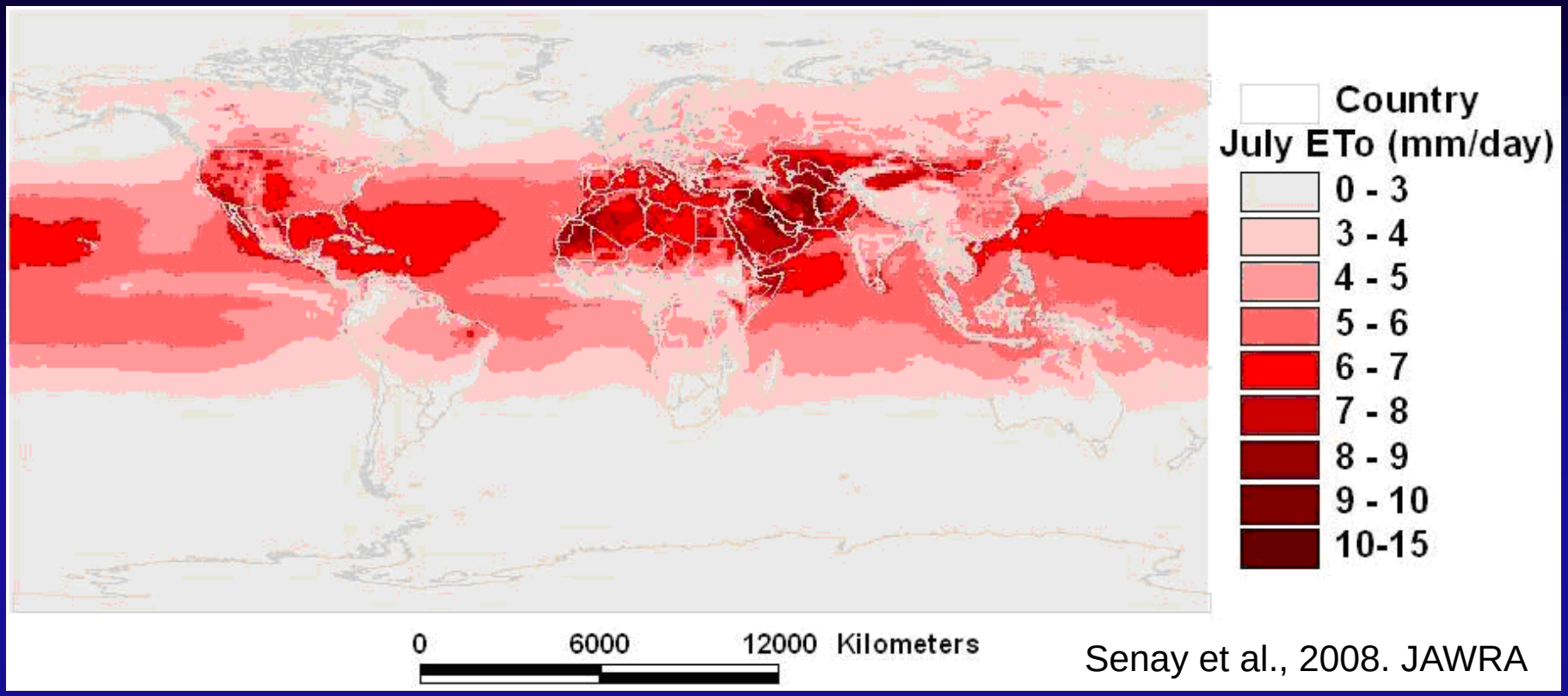
USGS

MODIS 8-day Land Surface Temperature (1-km spatial resolution)



USGS

Daily Global GDAS ETo for July 2004



Senay et al., 2008. JAWRA

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

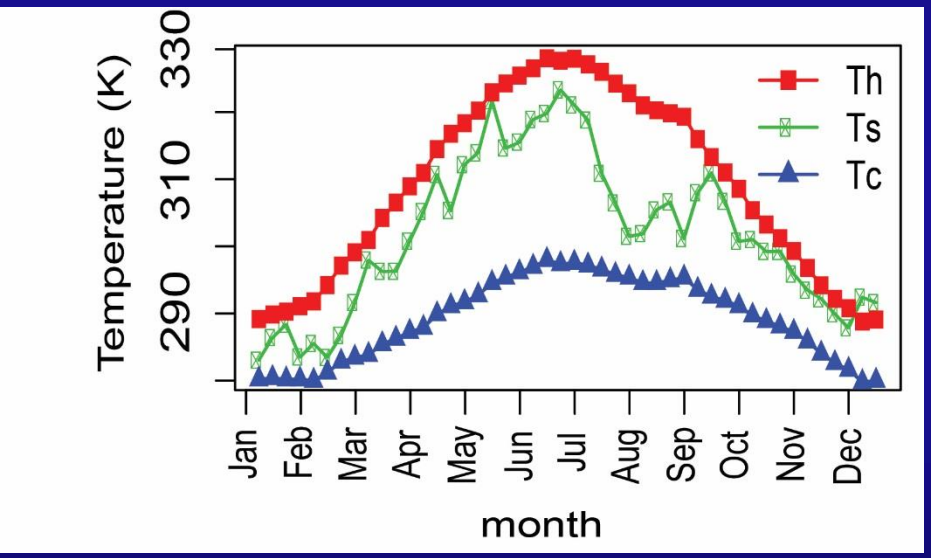
6-hr weather forecast data from NOAA: Radiation, temp, wind, RH and pressure to solve the standardized P-M Equation

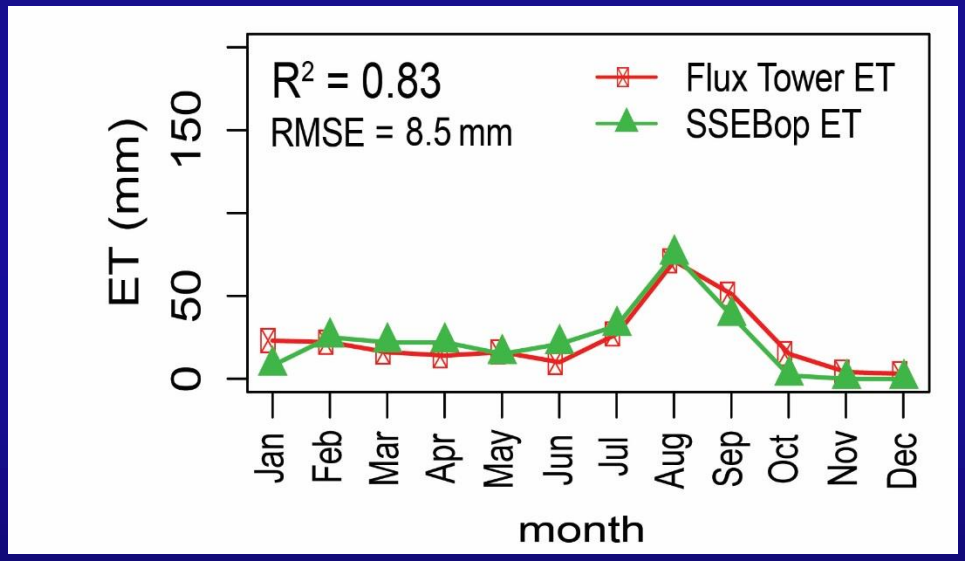
http://earlywarning.usgs.gov/Global/dwnglobalpet.php

USGS

SSEBop Illustrative Validation with EC Flux Towers

EC Flux Tower: Audubon, AZ, 2005





Senay et al., 2013. JAWRA

Inter-comparison of 4 ET Estimates

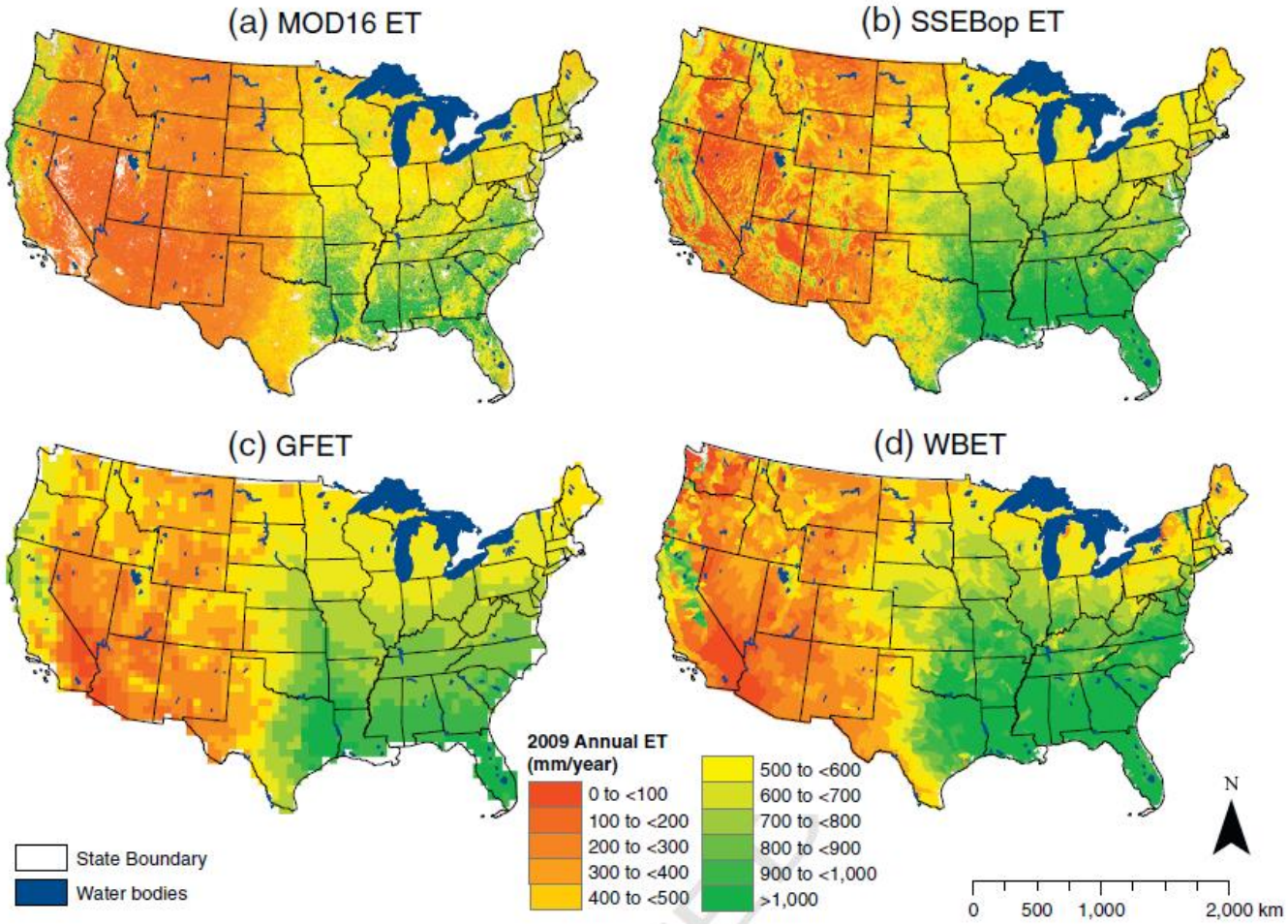


Fig. 8. Spatially explicit 2009 annual evapotranspiration datasets for the CONUS (a) MOD16 ET 1 km, (b) SSEBop ET 1 km, (c) gridded FLUXNET ET (GFET) 50 km and (d) HUC8 water balance ET (WBET).

Velpuri et al., 2013. RSE

USGS

FEWS NET Early Warning Website…

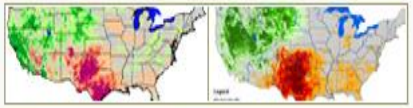
USGS
science for a changing world

USGS Home
Contact USGS
Search USGS

Home | Early Warning and Environmental Monitoring Program

Early Warning and Environmental Monitoring Program (EWEM)

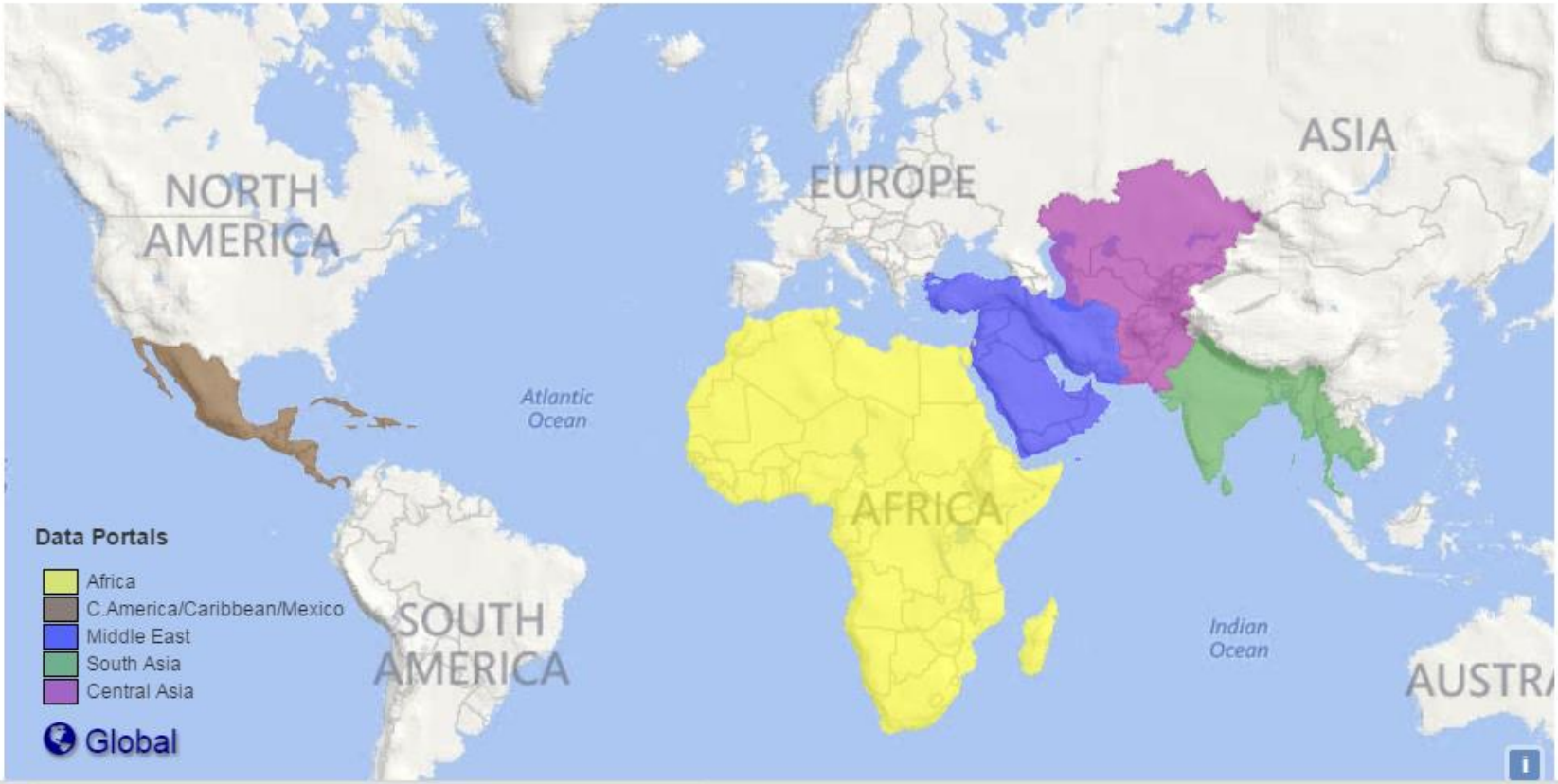
The Early Warning and Environmental Monitoring (EWEM) program encompasses a broad spectrum of scientific endeavors operating at national, regional , and international scales. EWEM project activities support investigations in the areas of climate change, natural resource management, environmental change detection, food security monitoring, water resource assessments, and hazard identification/mitigation.

Projects	Websites
Afghanistan	
Famine Early Warning Systems Network (FEWS NET)	
US Evapotranspiration Modeling Water Balance Model – Energy Balance Model	
NASA Livestock Early Warning System (NASA LEWS)	
Phenology / Drought Monitoring	

Active Monitoring Regions…

USGS FEWS NET Data Portal

The USGS FEWS NET Data Portal provides access to geo-spatial data, satellite image products, and derived data products in support of FEWS NET monitoring needs throughout the world. This portal is provided by the USGS FEWS NET Project, part of the Early Warning and Environmental Monitoring Program at the USGS Earth Resources Observation and Science (EROS) Center.

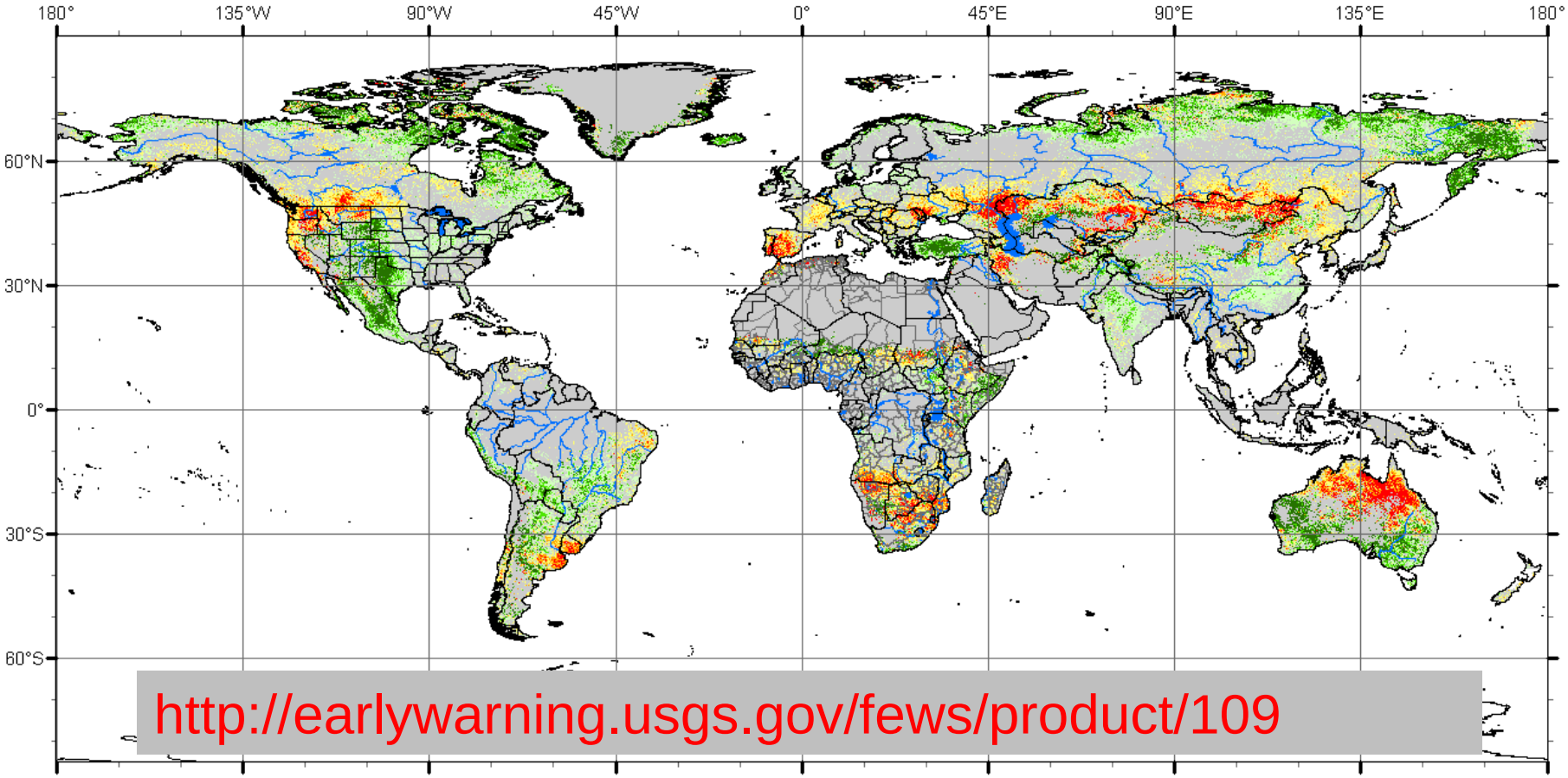


Global ET Anomaly

- ET Model: SSEBop
- Remote Sensing: MODIS/Aqua
- ET Anomaly: %median of (2003-2013)
  - Seasonal ET as percent of the median
    - March to October : Northern Hemisphere Focus
    - October to March: Southern Hemisphere Focus

Cumulative ETa Anomaly: Mar Dekad 1 - Aug Dekad 3, 2015

Percent of Median (2003-2013)



http://earlywarning.usgs.gov/fews/product/109

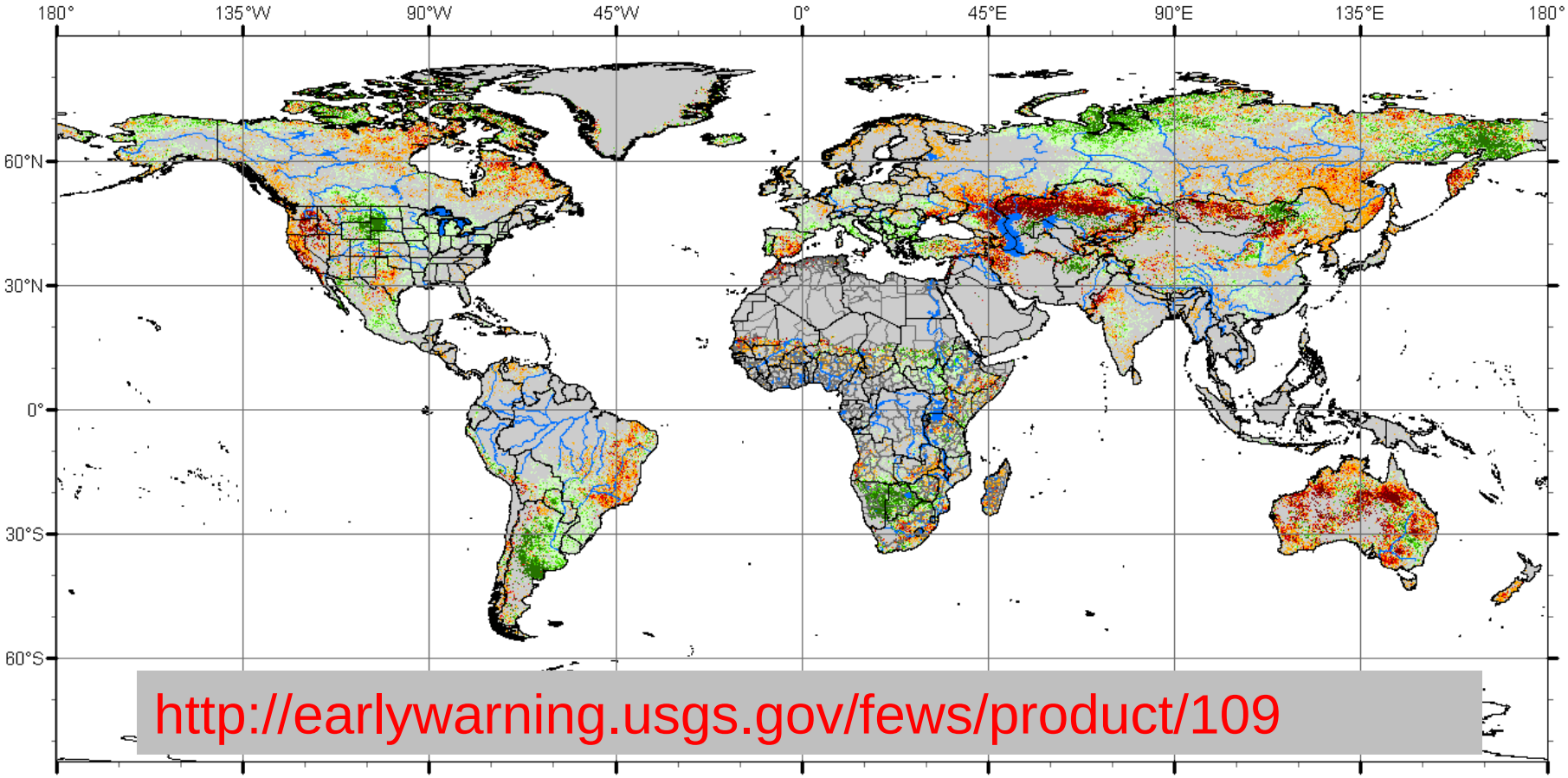
ETa Anomaly (%)

< 50 | 50-70 | 70-90 | 90-110 | 110-130 | 130-150 | >150

Map Produced by USGS/EROS

Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2014

Percent of Median (2003-2013)



http://earlywarning.usgs.gov/fews/product/109

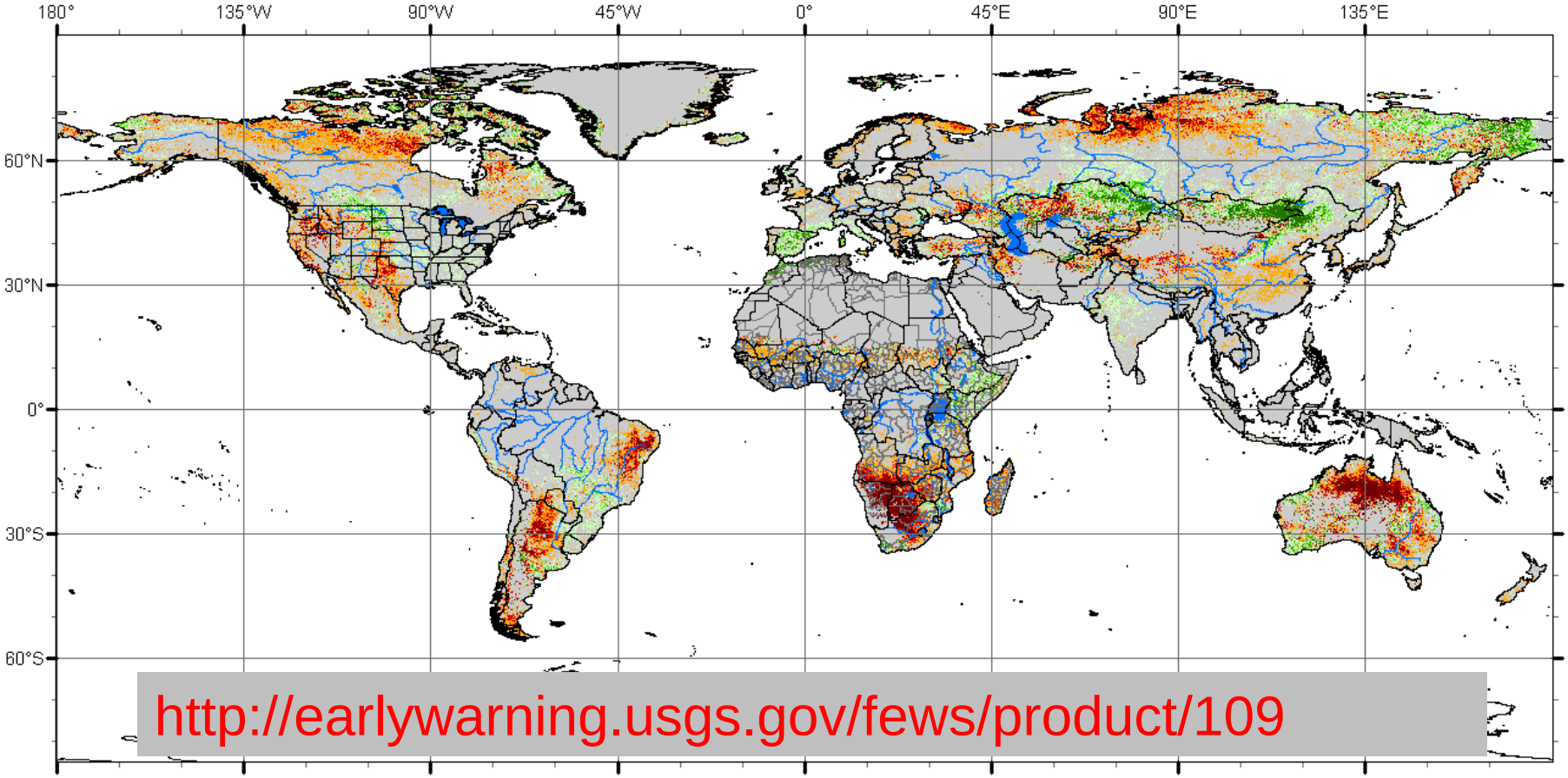
ETa Anomaly (%)

< 50	50 - 70	70 - 90	90 - 110	110 - 130	130 - 150	> 150

Map Produced by USGS/EROS

Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2013

Percent of Average (2003-2013)



http://earlywarning.usgs.gov/fews/product/109

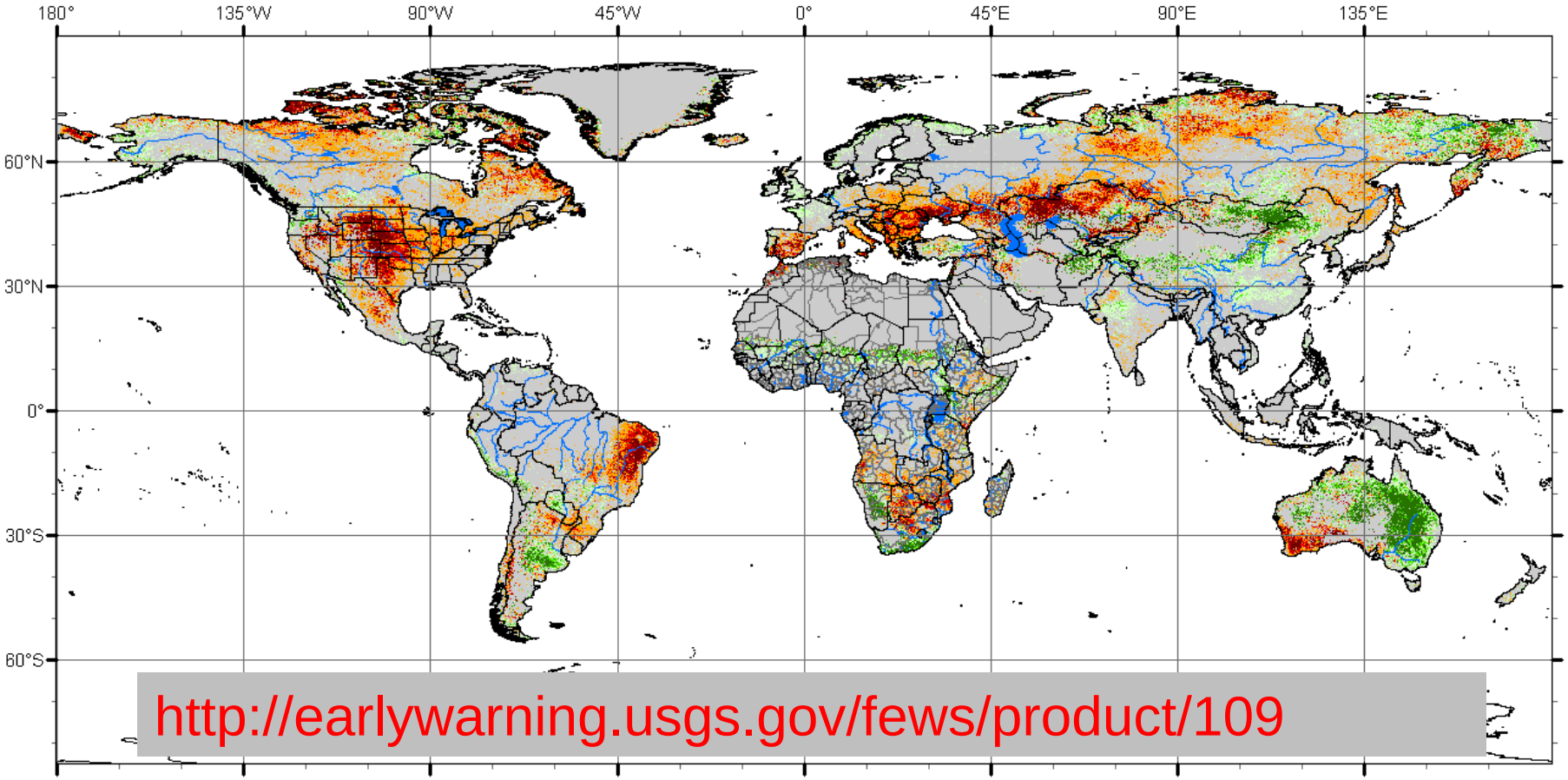
ETa Anomaly (%)

< 50 | 50 - 70 | 70 - 90 | 90 - 110 | 110 - 130 | 130 - 150 | > 150

Map Produced by USGS/EROS

Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2012

Percent of Average (2003-2013)



http://earlywarning.usgs.gov/fews/product/109

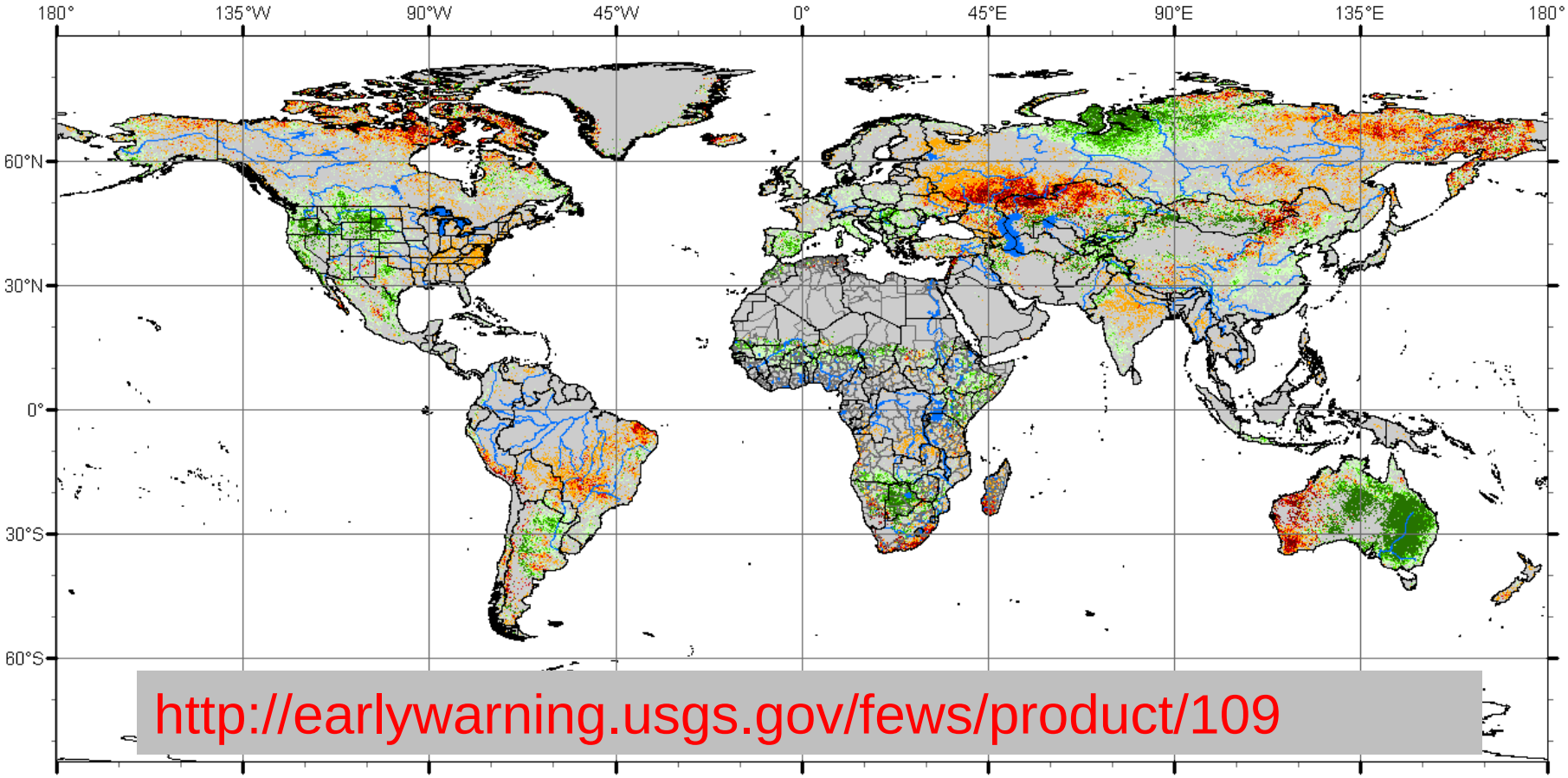
ETa Anomaly (%)

< 50 | 50 - 70 | 70 - 90 | 90 - 110 | 110 - 130 | 130 - 150 | > 150

Map Produced by USGS/EROS

Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2010

Percent of Median (2003-2013)



http://earlywarning.usgs.gov/fews/product/109

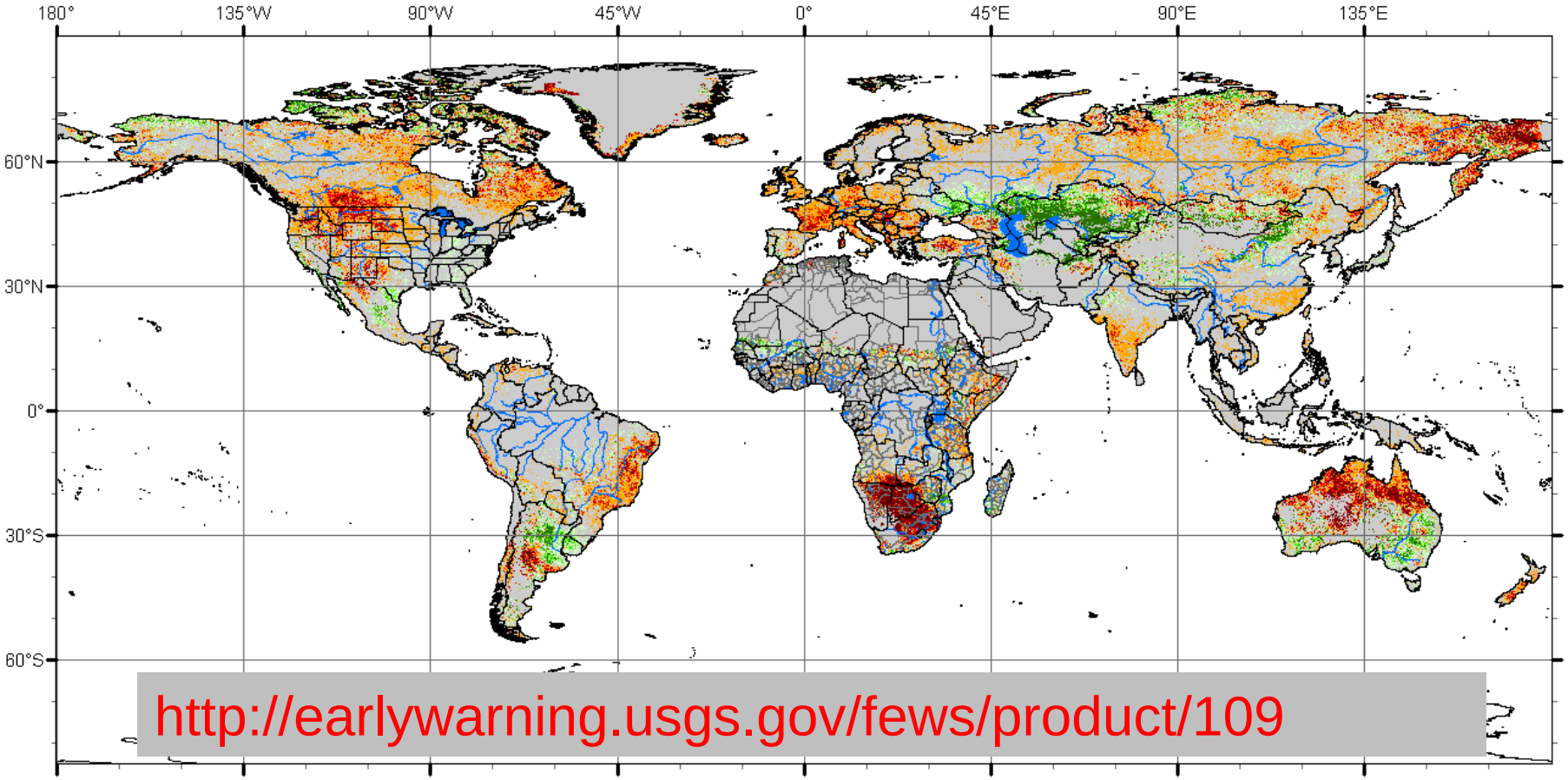
ETa Anomaly (%)

< 50 | 50 - 70 | 70 - 90 | 90 - 110 | 110 - 130 | 130 - 150 | > 150

Map Produced by USGS/EROS

Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2003

Percent of Median (2003-2013)



http://earlywarning.usgs.gov/fews/product/109

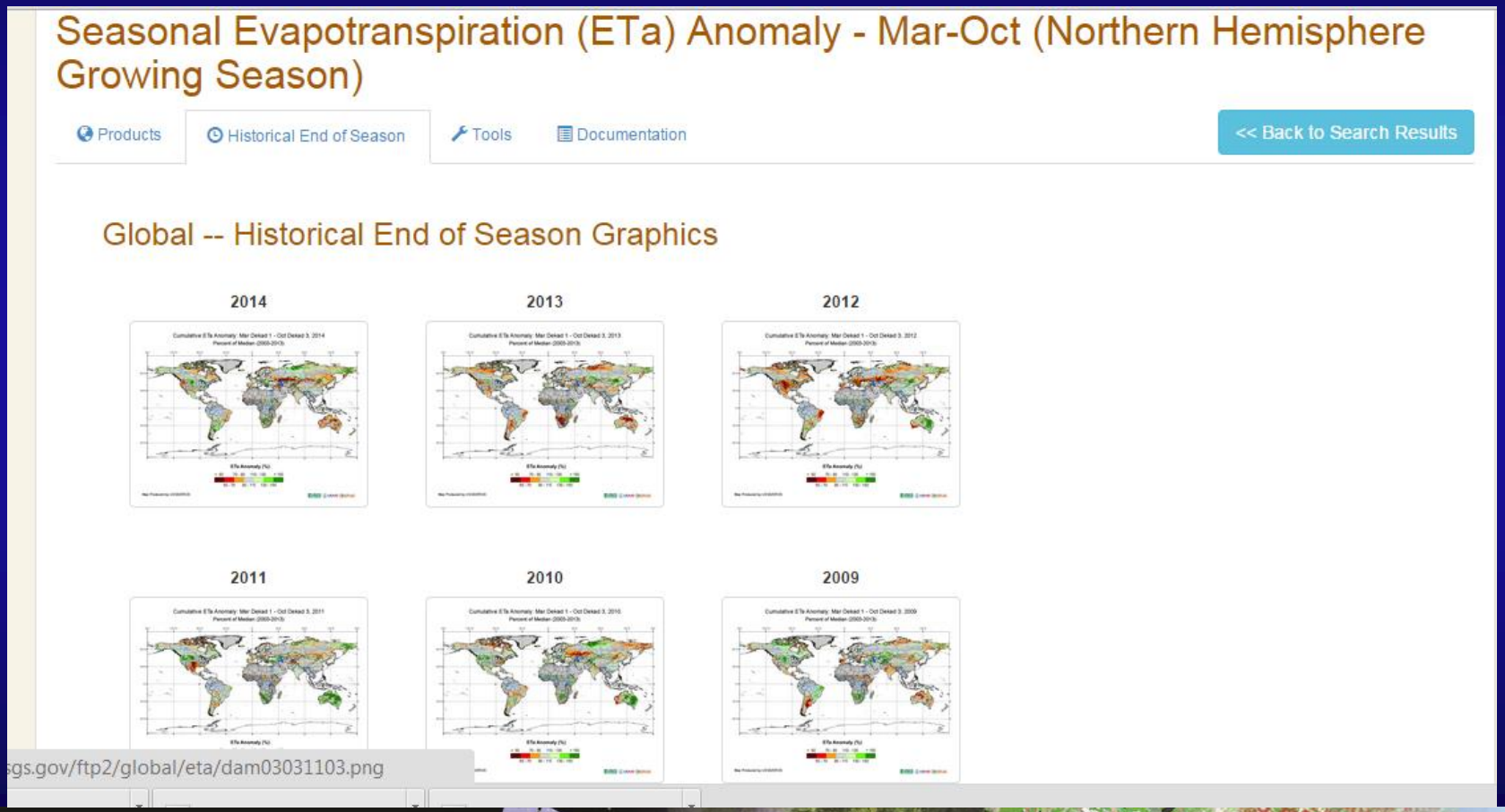
ETa Anomaly (%)

< 50 | 50 - 70 | 70 - 90 | 90 - 110 | 110 - 130 | 130 - 150 | > 150

Map Produced by USGS/EROS

Historical graphics available at:

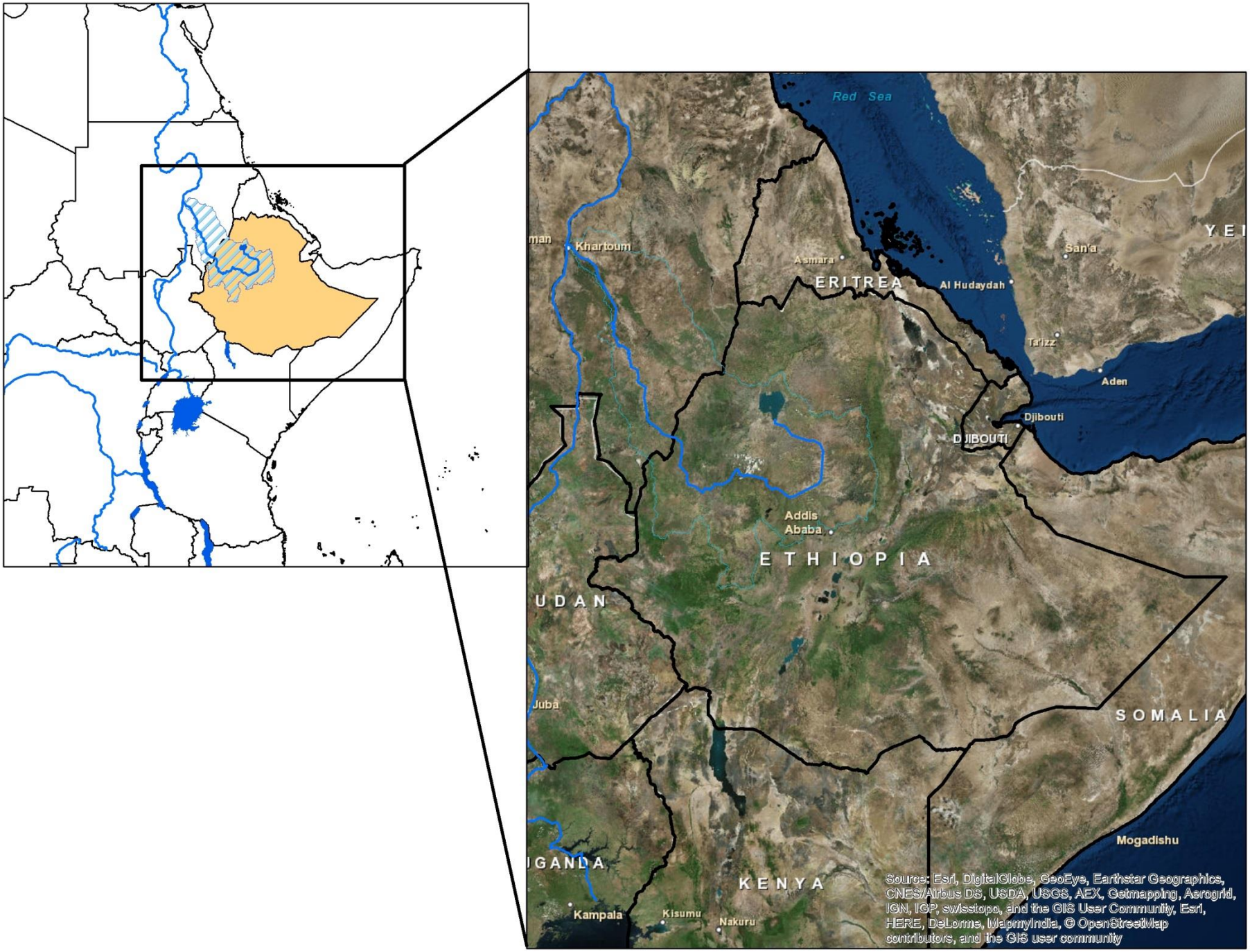
http://earlywarning.usgs.gov/fews/product/109



USGS

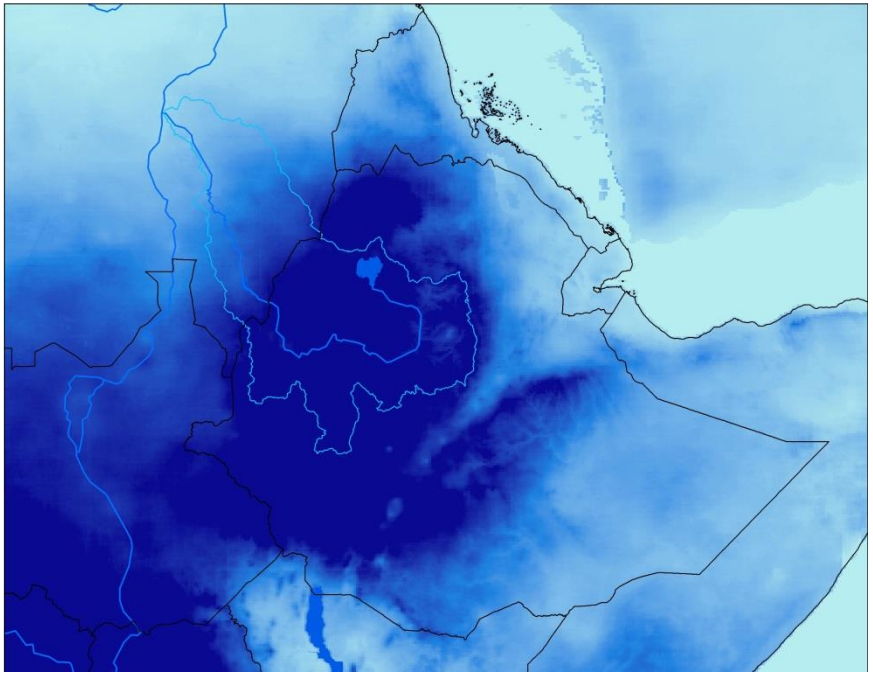
Nile Basin Water Balance Dynamics

- ET: SSEBop
- ET Anomaly: %median using MODIS/Aqua (2003 – 2013)
- Precipitation:
  - Annual: TRMM/CHIRPS (FEWS NET/ USCB)
    - Blend of satellite and station rainfall


Red Sea
Khartoum
Asmara
ERITREA
Al Hudaydah
San'a
Ta'izz
Aden
Djibouti
DJIBOUTI
Addis Ababa
ETHIOPIA
UDAN
Juba
SOMALIA
Mogadishu
IGANDA
KENYA
Kampala
Kisumu
Nakuru
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Median Annual Distribution

Rainfall (CHIRPS)



PPT source: CHIRPS

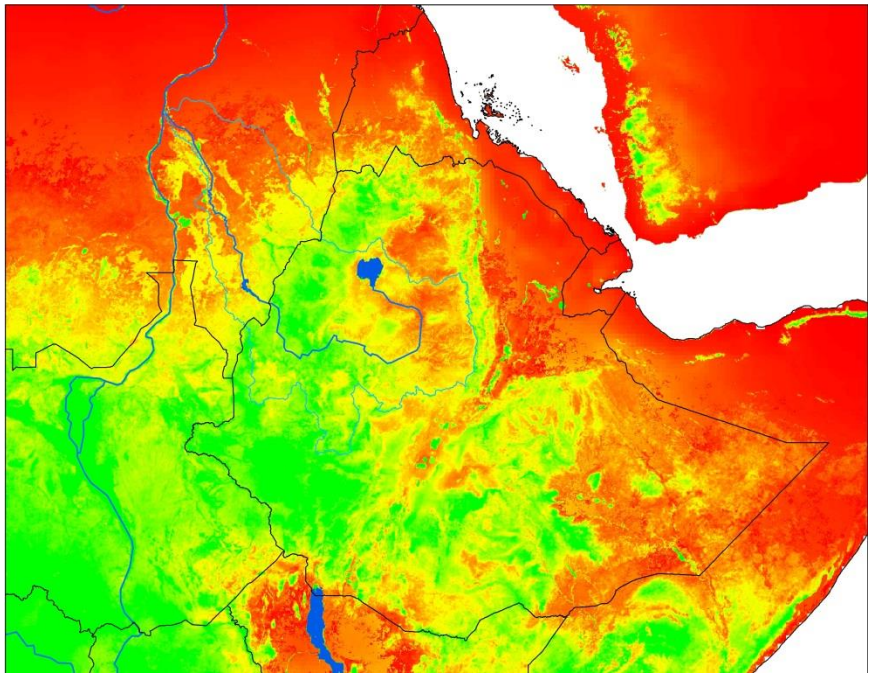
PPT.tif

mm

1000

0

ETa (SSEBop)

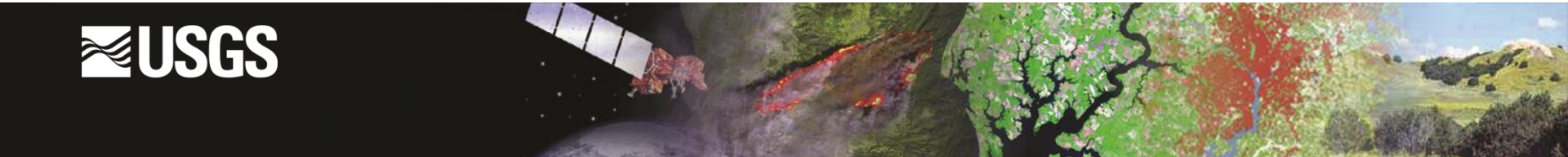


ETa (2003-2013)

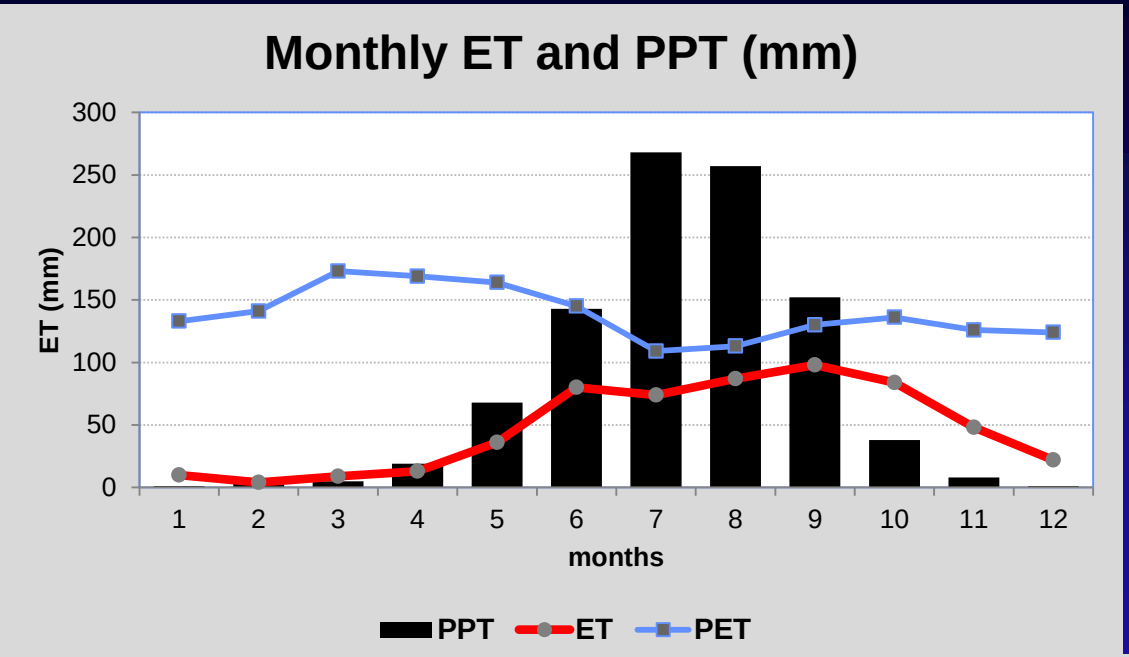
mm

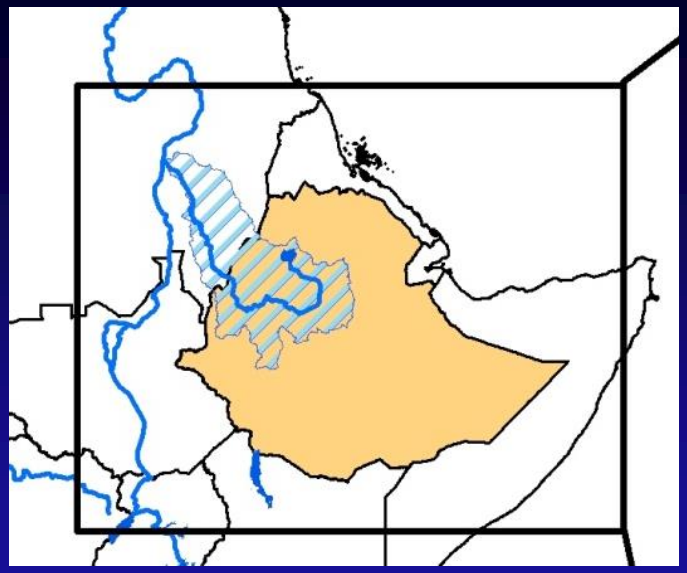
1200

0



Blue Nile Basin

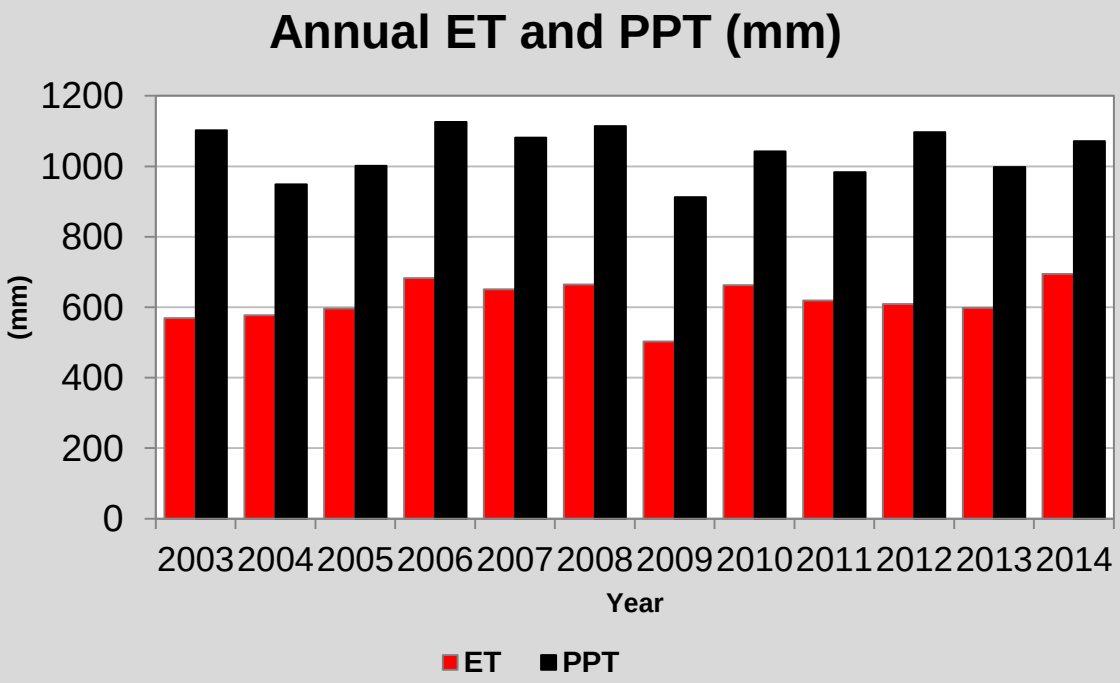




Estimates!

Avg PPT = 1040 mm
Avg ET = 619 mm
ET/PPT = 0.6

40% Runoff??

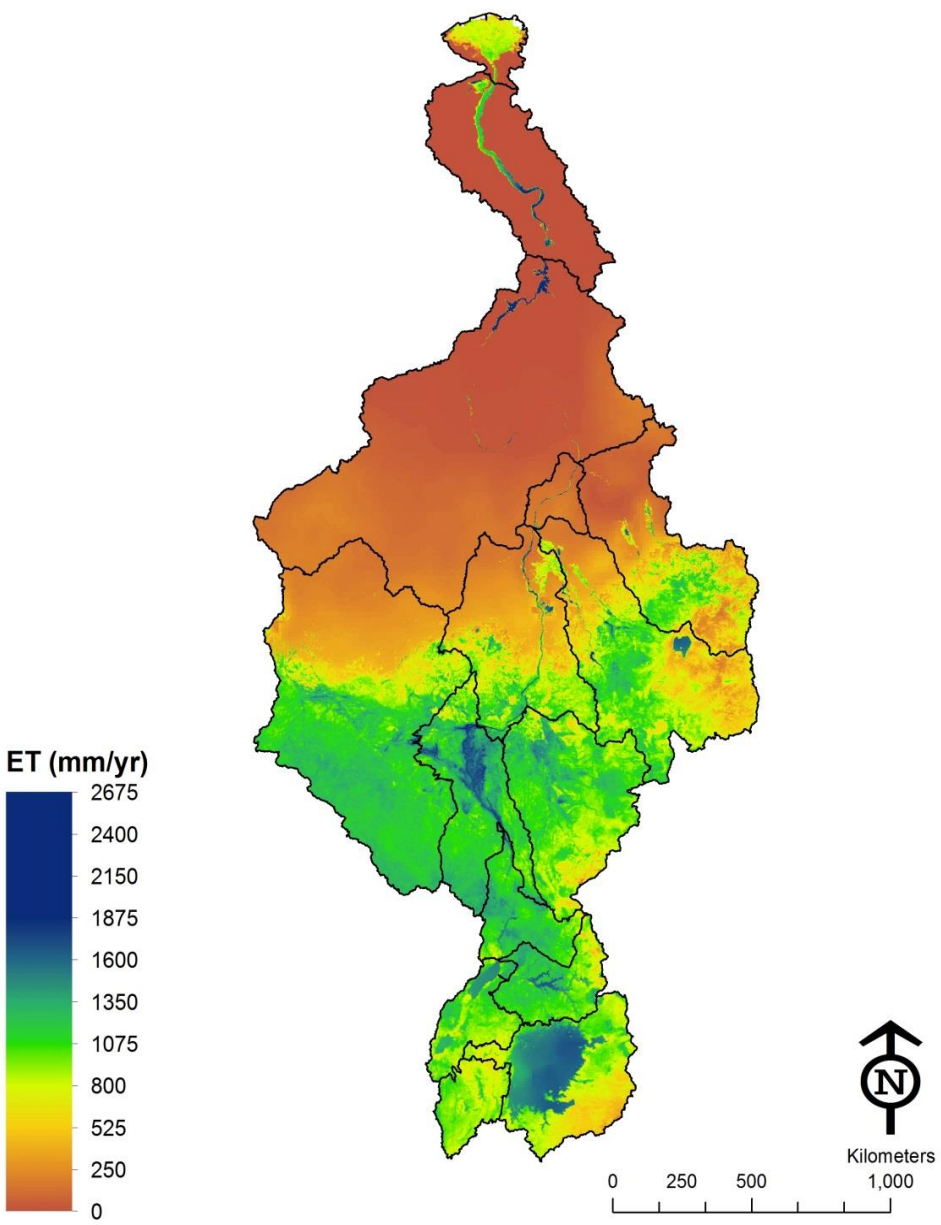


Bastiaanssen et al, 2014.
Alemu et al, 2014.

Remote Sensing Special issue: Earth Observation for Water Resource Management in Africa

Distribution of the annually accumulated actual evapotranspiration across the Nile Basin averaged for the period 2005 to 2010. The pixel size is 1 km

SSEBop ET

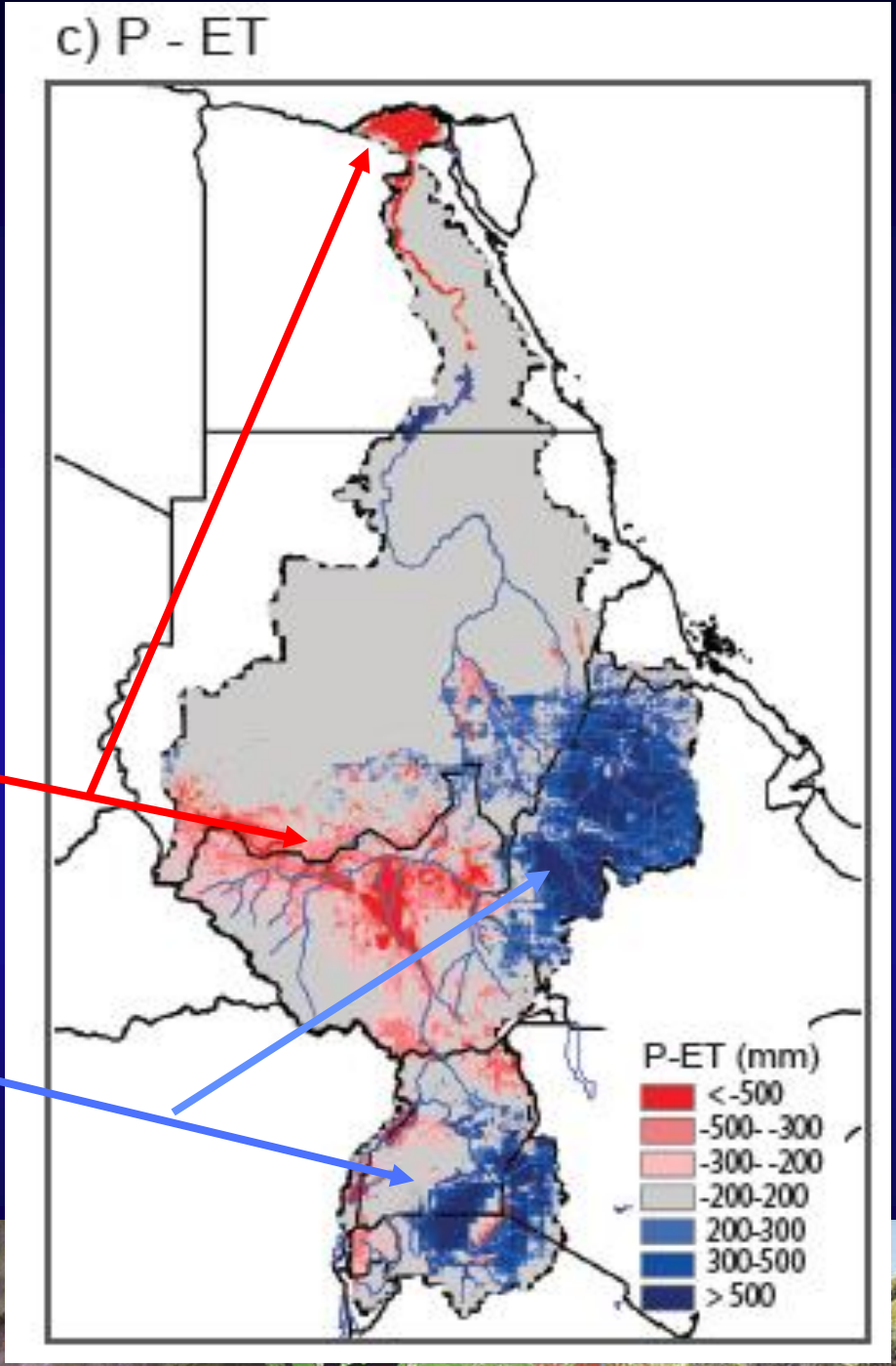


Annual Water Balance Distribution (P-ET), 1 km

Senay et al, 2014. WRR

Sink

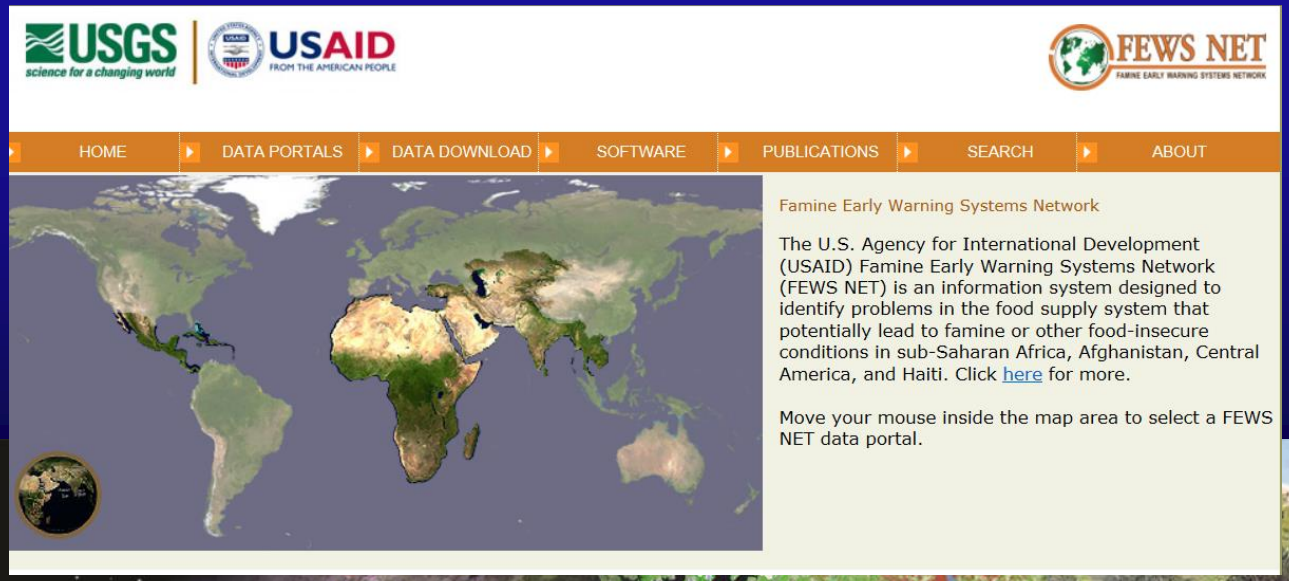
Source



Greater Horn of Africa Regional Operational ET Anomaly Products

MODIS: Aqua Sensor since 2003

ET anomalies are created as percent deviation (ratio) from the median over (2003-2013) ET datasets.

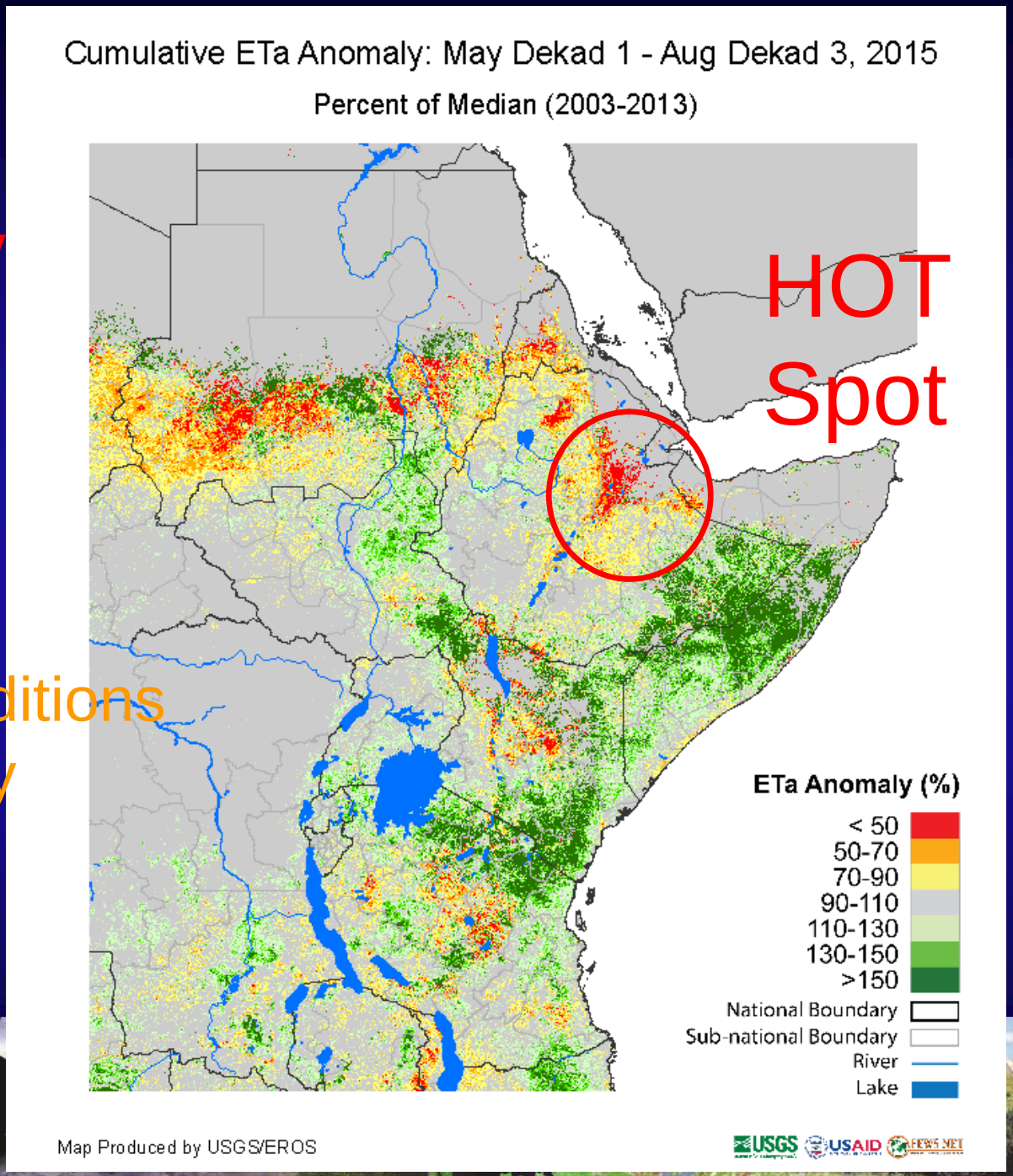


USGS

Recent ET Anomaly (May-August)

Showing below normal ET

Severe drought conditions In the Afar Rift Valley



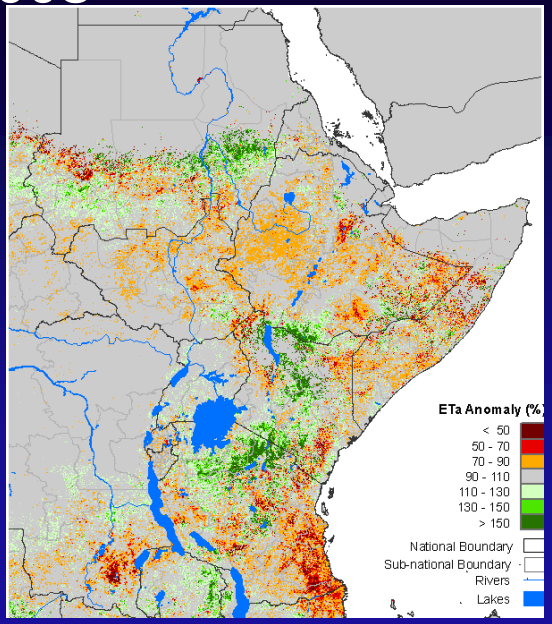
USGS

Historical ET Anomaly:
May to September since 2003

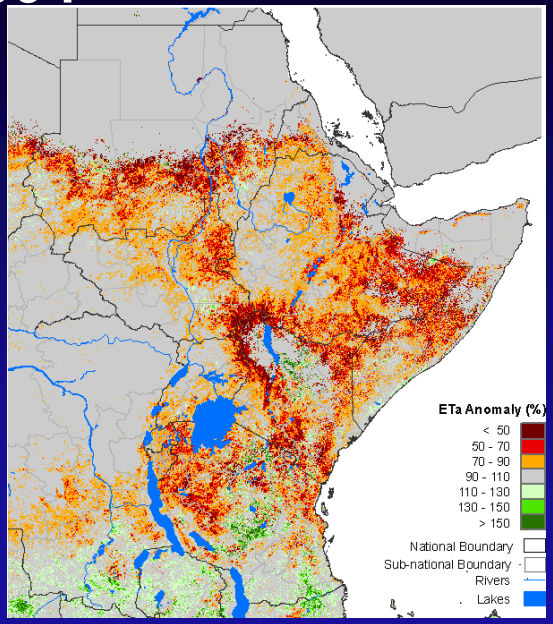
USGS

May - Sep

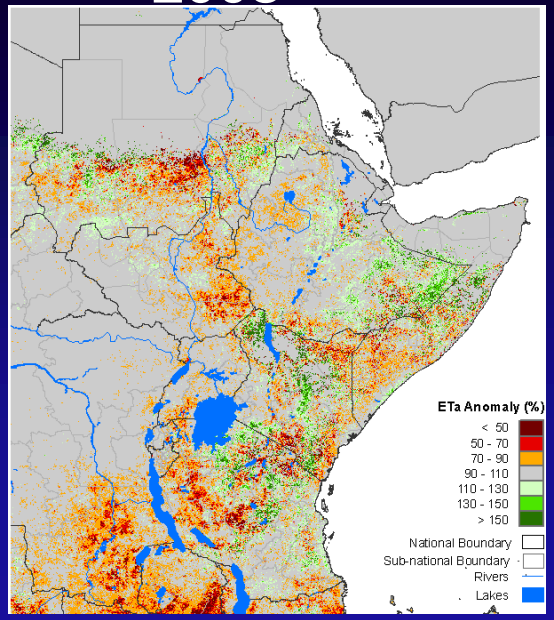
2003



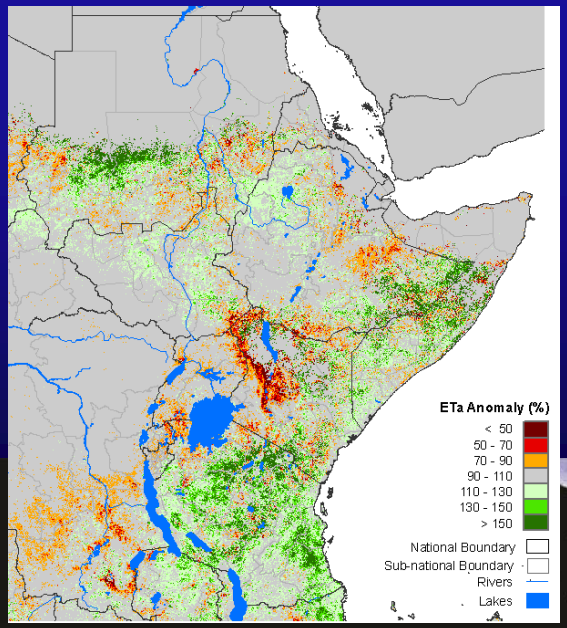
2004



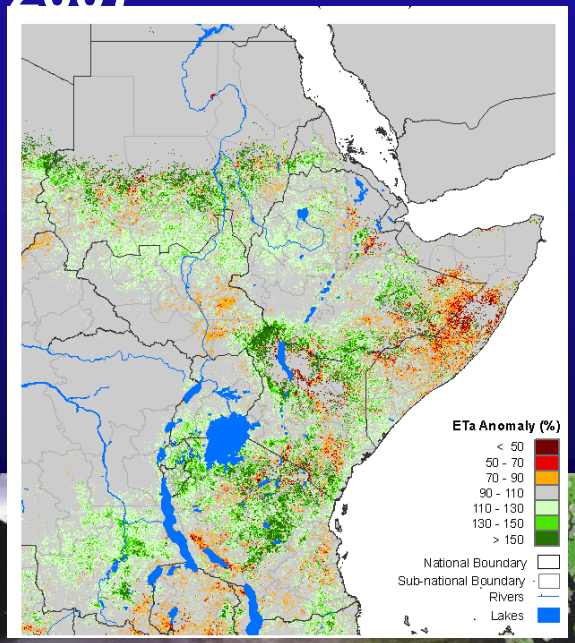
2005



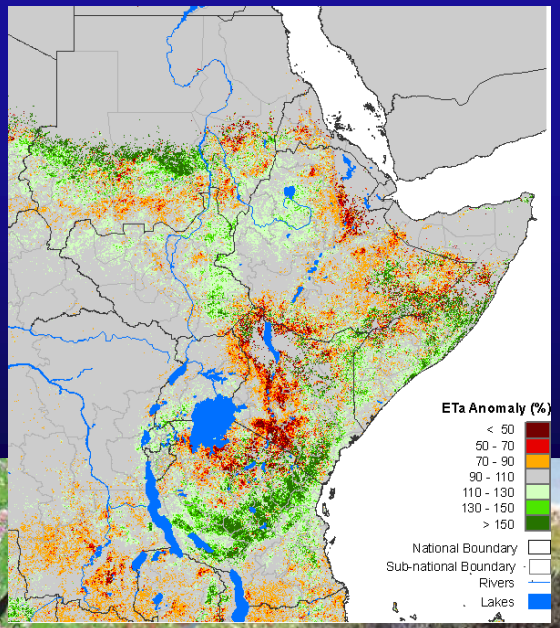
2006



2007

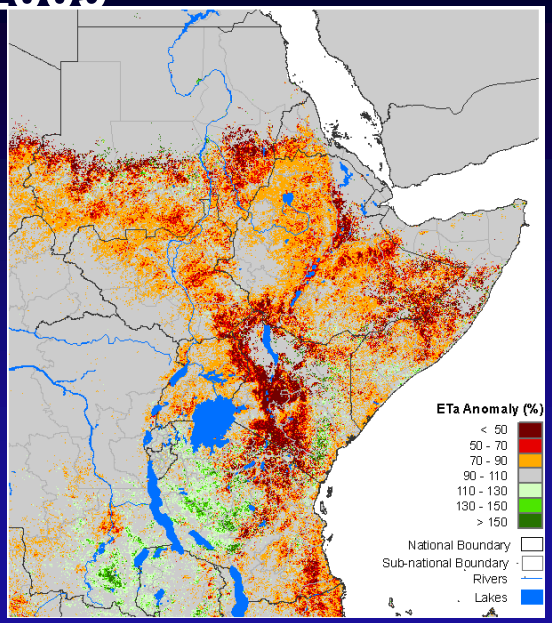


2008

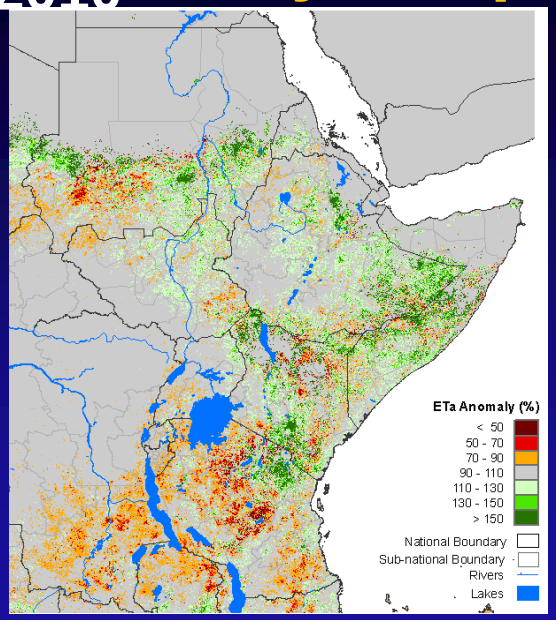


May - Sep

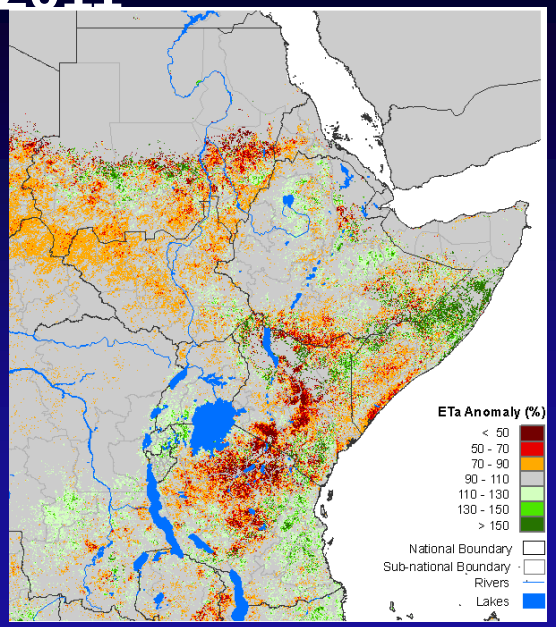
2009



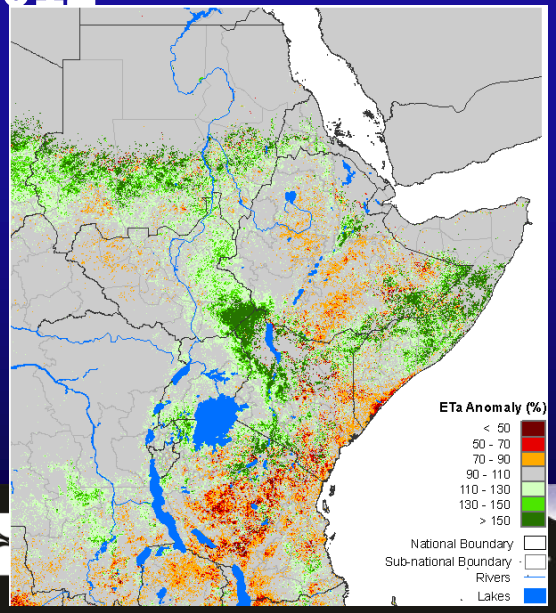
2010



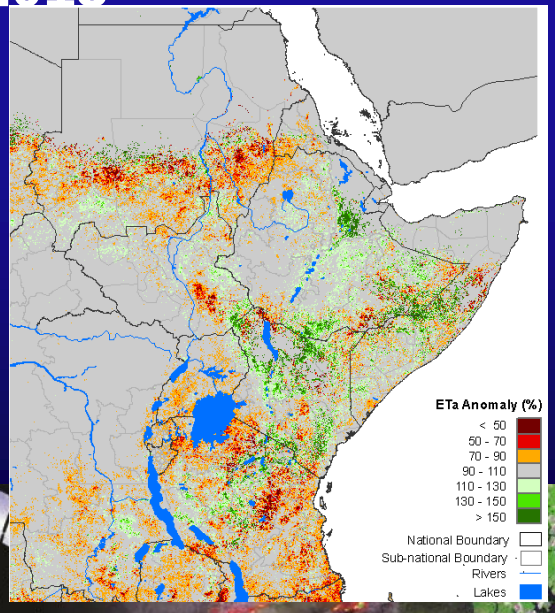
2011



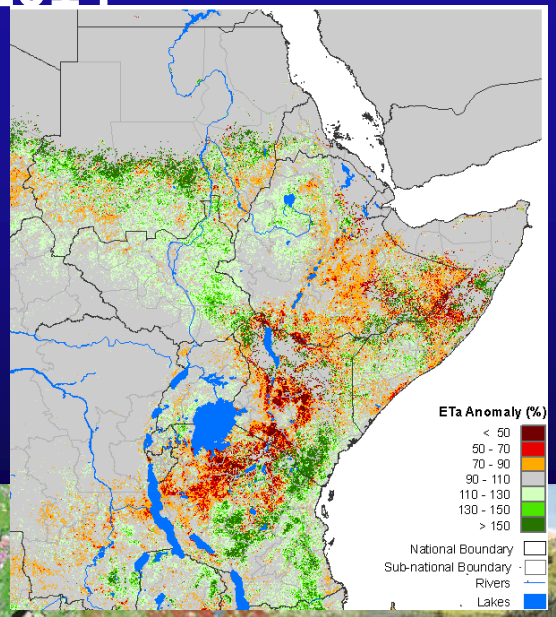
2012



2013

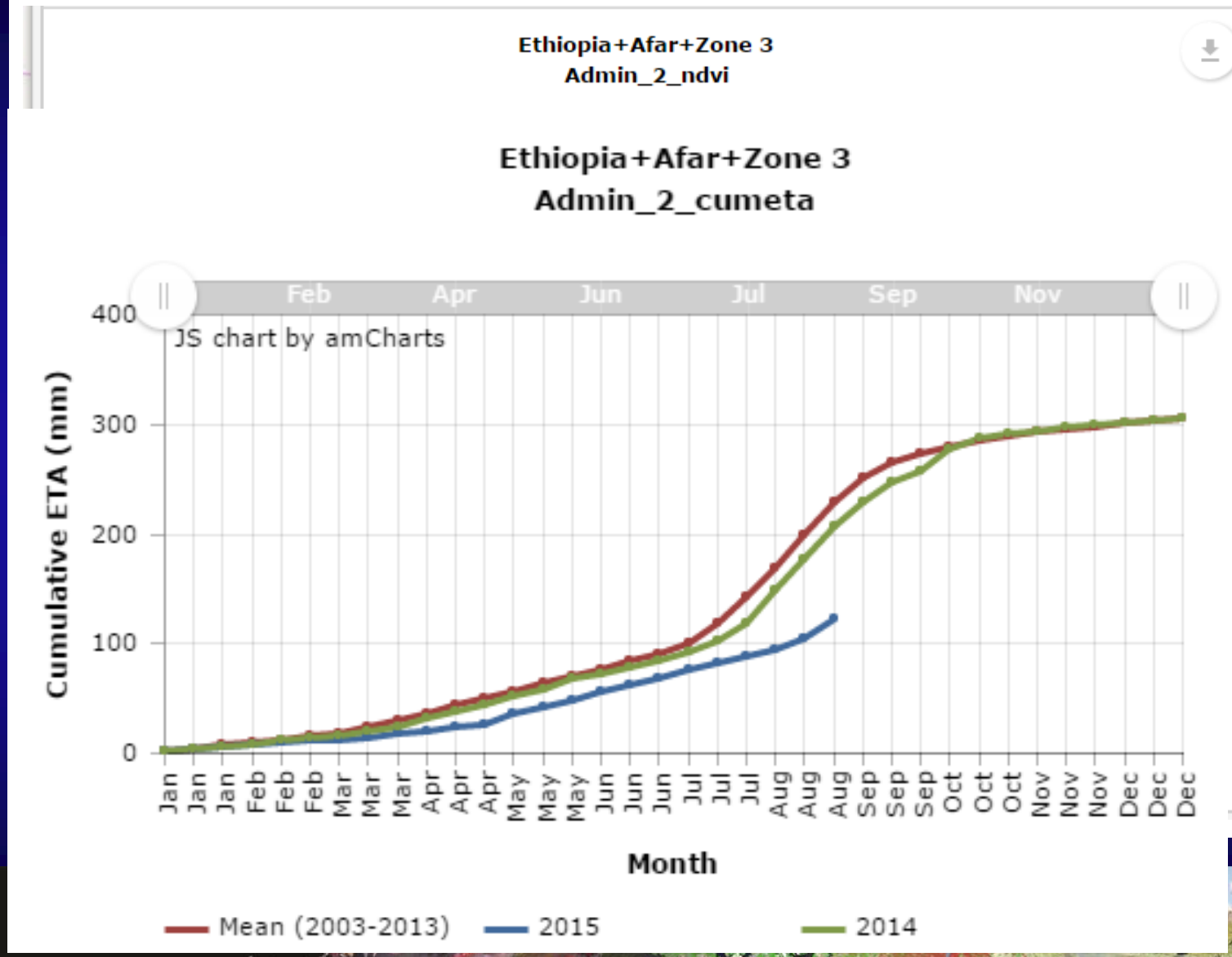


2014



Convergence of Evidence

Rainfall
NDVI
ET



USGS

FEWS NET Food Security Outlook

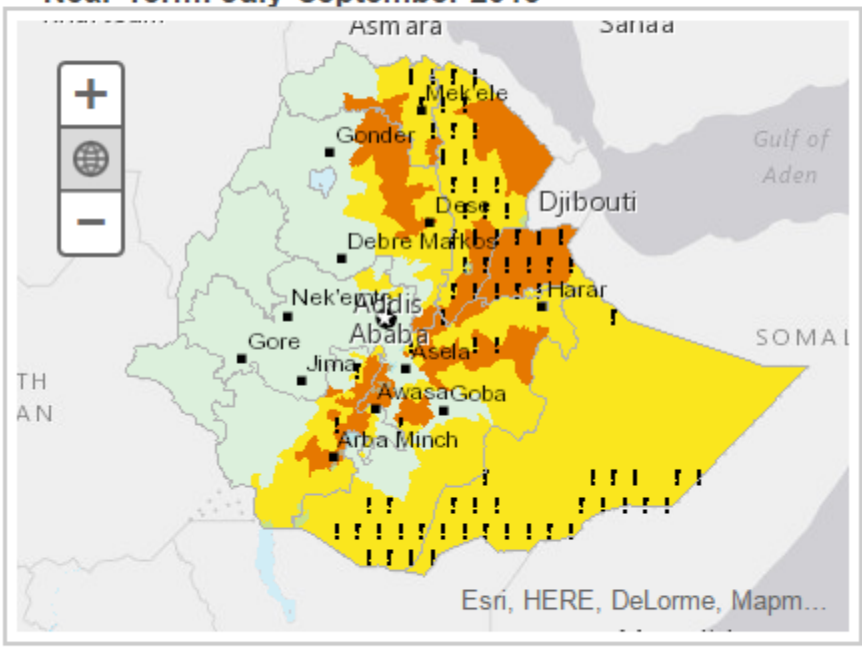
Food Security Outlook Update

Archive

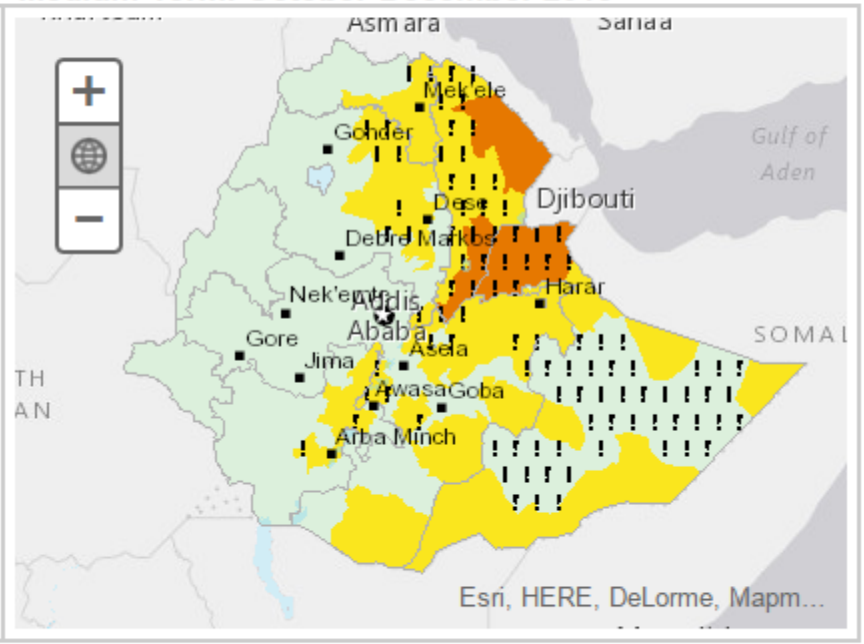
Livestock deaths continue in Afar and Sitti Zone

August 2015

Near Term: July-September 2015



Medium Term: October-December 2015

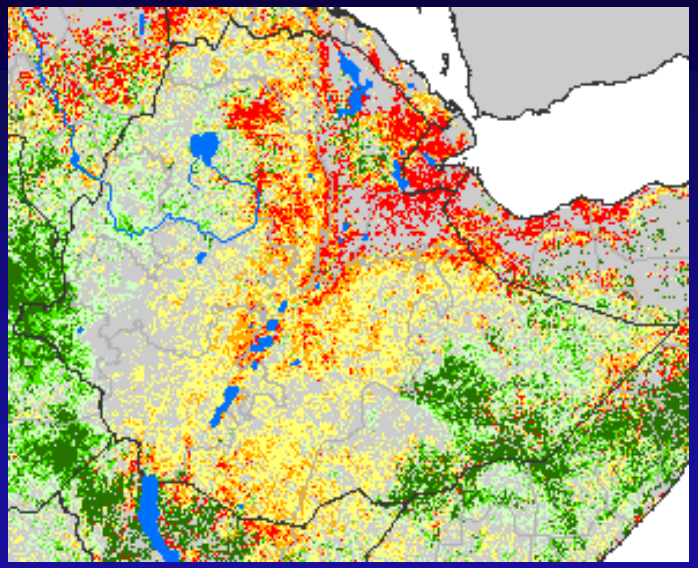


IPC V2.0 Phase of Acute Food Insecurity

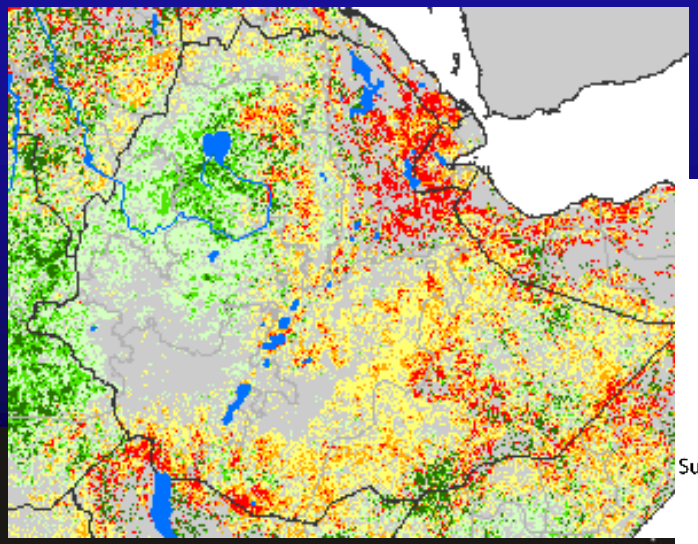
Minimal	Stressed	Crisis	Emergency	Famine

Would likely be worse without current or programmed humanitarian assistance

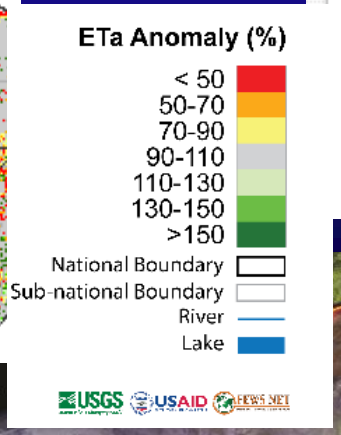
ET Anomaly: Jan - July

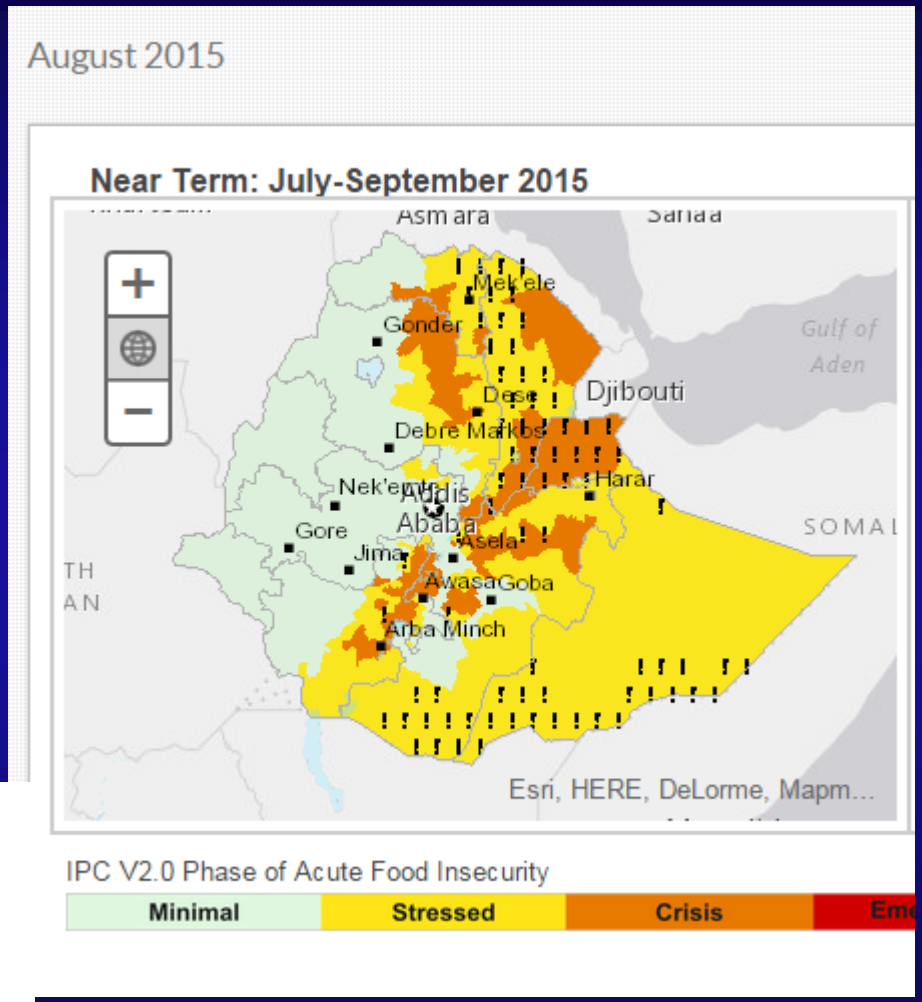


2015



2014



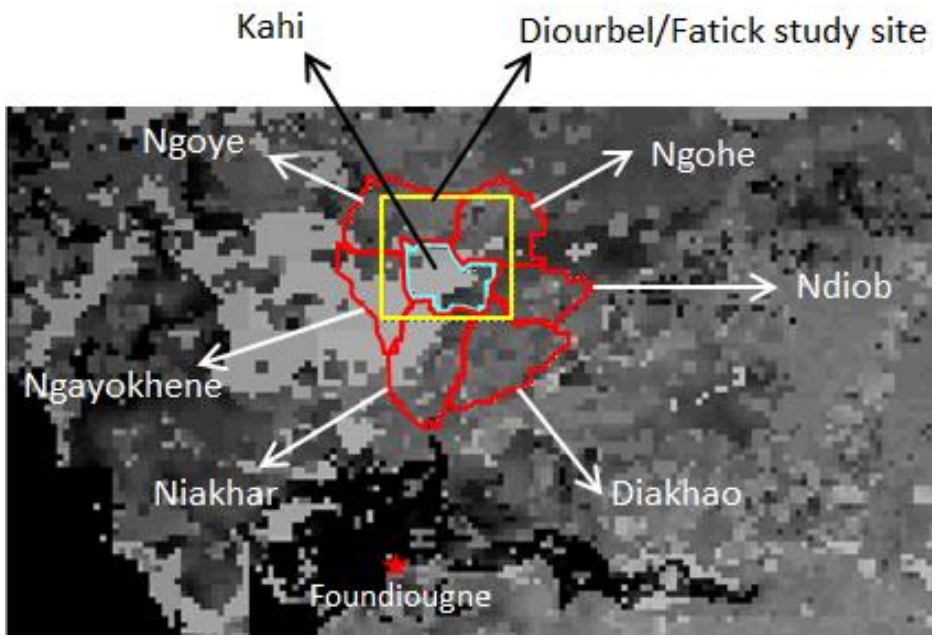


ET for Developing Crop Insurance Payout Scheme

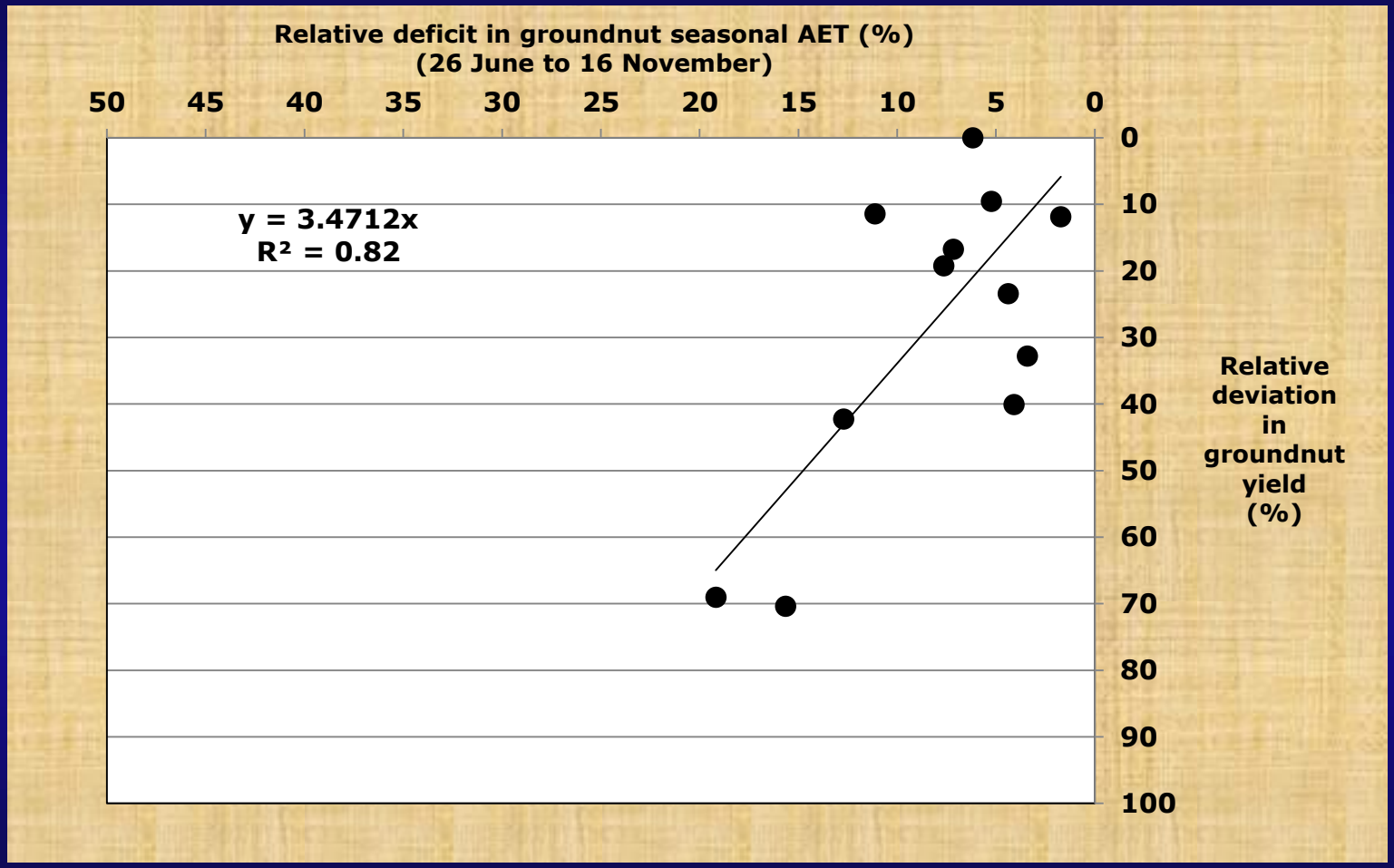
(Harri Jayanthi, USGS/FEWS NET)

USGS

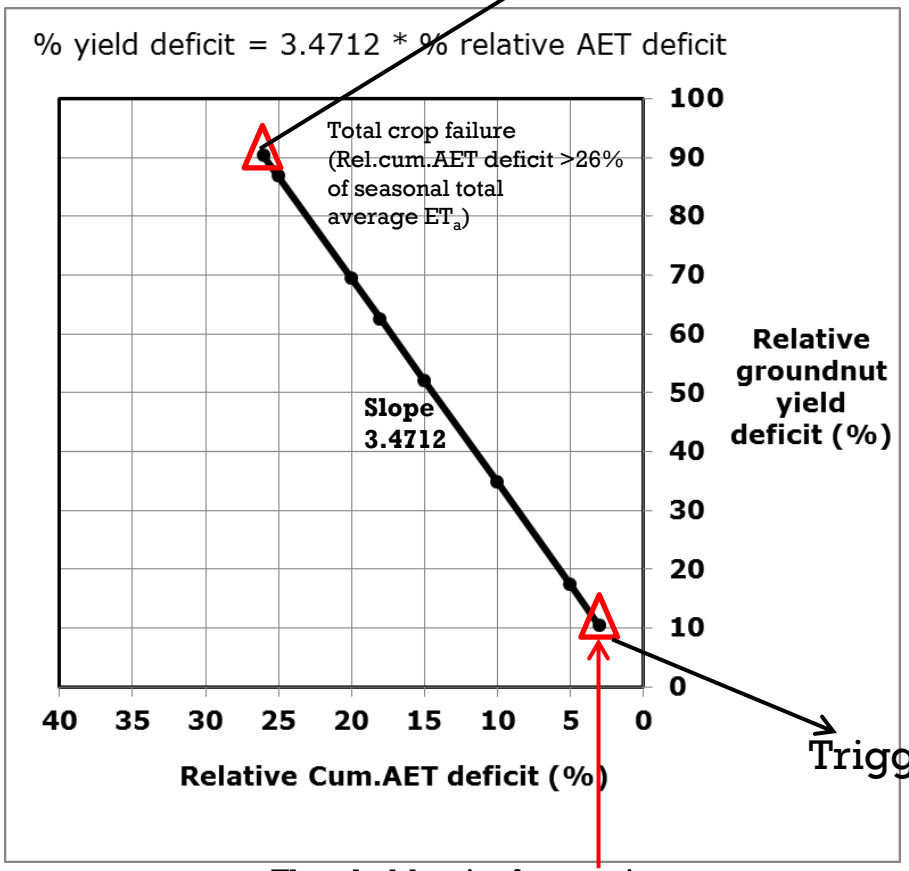
Proof-of-Concept Crop Insurance Application: Senegal, Africa

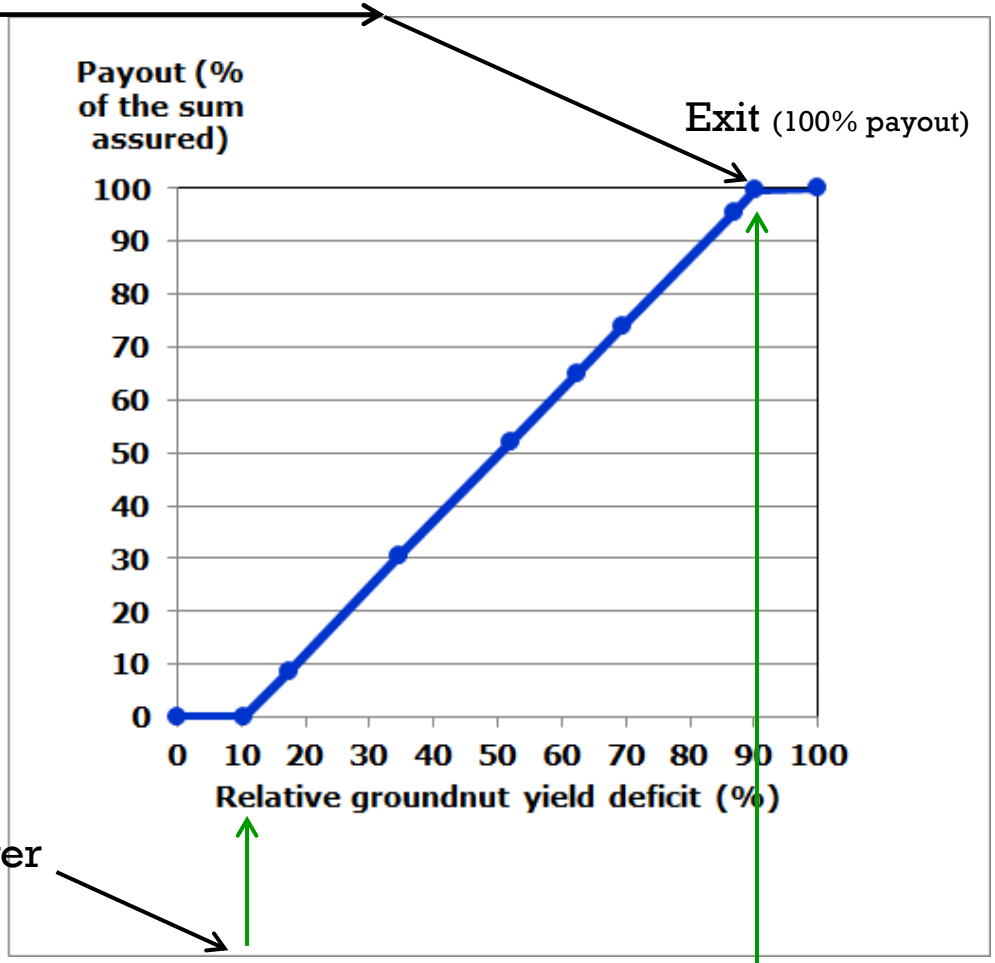


Relating ET Reduction to Crop Yield reduction (Groundnut, Senegal)



Method of constructing an insurance product
(based on groundnut drought vulnerability function)





Trigger

Threshold point for starting payout
(Rel.cum.AET. deficit > 3%)

Threshold point for starting payout
(Rel.yield. deficit > 10%)

Total crop failure
(Rel.cum.AET deficit>26% of the seasonal total average ET_a)

USGS science for a changing world
USAID FROM THE AMERICAN PEOPLE
FEWS NET FAMINE EARLY WARNING SYSTEMS NETWORK

Conclusion

Remote sensing and hydrologic modeling can provide globally consistent and locally relevant data and information.

- **1) To monitor landscape response anomalies every 1 Km^2, every dekad--globally**
  - **for drought early warning**
- **2) To map and quantify crop water use volumes**
  - **for planning and designing irrigation systems**
- **3) To understand better the relationships between water supply and water use**
  - **For improved basin-wide water management**
- **4) Challenge remains for local decision makers to adopt remote sensing based tools and products for their daily operations.**

USGS