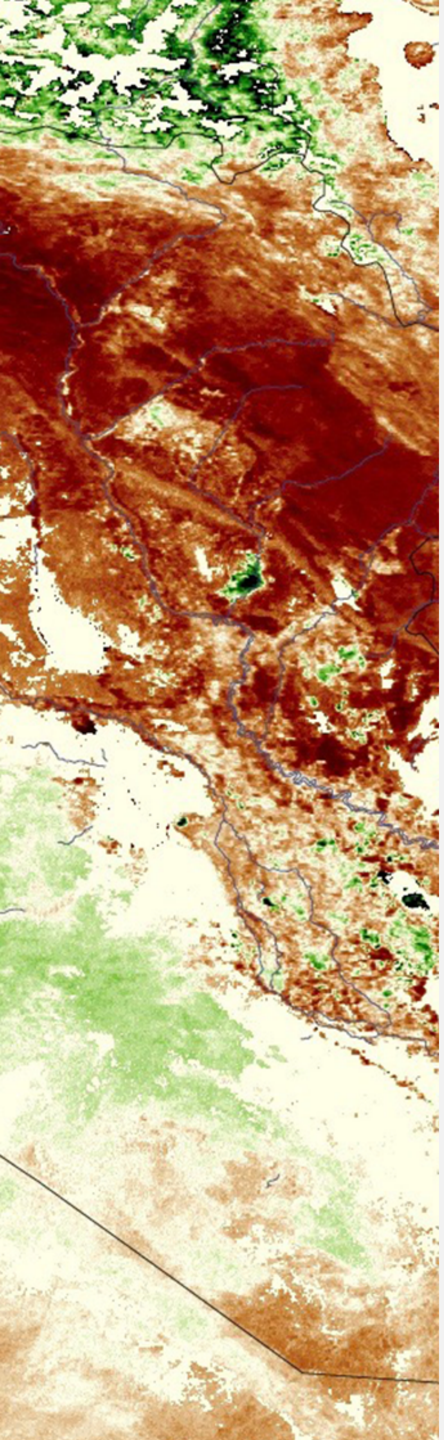


National Aeronautics and
Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

Remote Sensing of Drought

July 12, 2017

Week 1

Speakers: Amber McCullum amberjean.mccullum@nasa.gov

Amita Mehta amita.v.mehta@nasa.gov

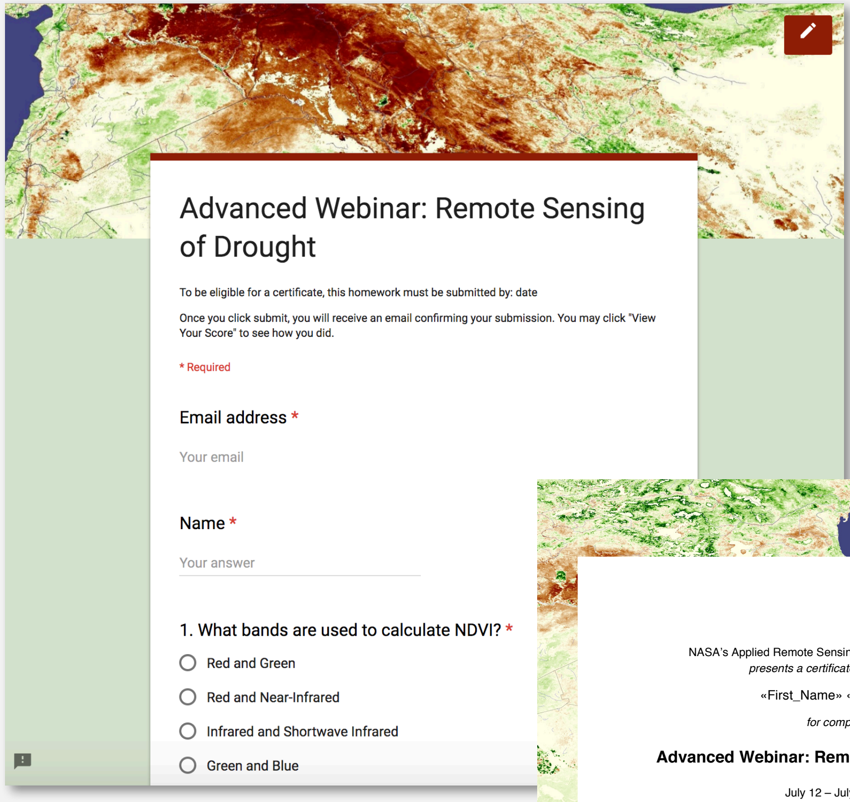
Cynthia Schmidt cynthia.l.schmidt@nasa.gov

Course Structure

- Two, 2-hour sessions: Wednesday, July 12, and Wednesday, July 19
- Each session will be given twice:
  – Session A: 12:00 – 2:00 p.m. EDT (UTC-4)
  – Session B: 9:00 – 11:00 p.m. EDT (UTC-4)
- Presentations:
  – Demonstration of Drought Monitoring and Drought Data Access Tools
  – Drought Data Access
  – Drought Analysis Exercise with QGIS: Case Study, California
- Homework Exercise: Drought Monitoring Over Northern Africa
- Q and A after each session, and by email to instructors

Homework and Certificates

- Homework
  - Answers must be submitted via Google Form
- Certificate of Completion:
  - Attend both webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
    - HW Deadline: August 2nd
  - You will receive certificates approx. two months after the completion of the course from: marines.martins@ssaihq.com



Advanced Webinar: Remote Sensing of Drought

To be eligible for a certificate, this homework must be submitted by: date

Once you click submit, you will receive an email confirming your submission. You may click "View Your Score" to see how you did.

* Required

Email address *

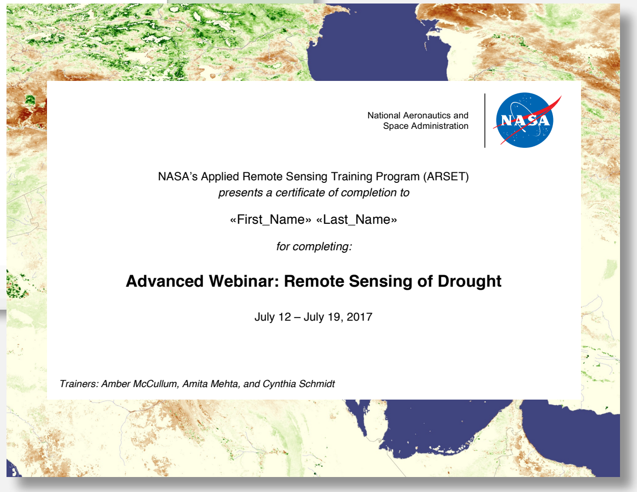
Your email

Name *

Your answer

1. What bands are used to calculate NDVI? *

- Red and Green
- Red and Near-Infrared
- Infrared and Shortwave Infrared
- Green and Blue



National Aeronautics and Space Administration

NASA's Applied Remote Sensing Training Program (ARSET)

presents a certificate of completion to

«First_Name» «Last_Name»

for completing:

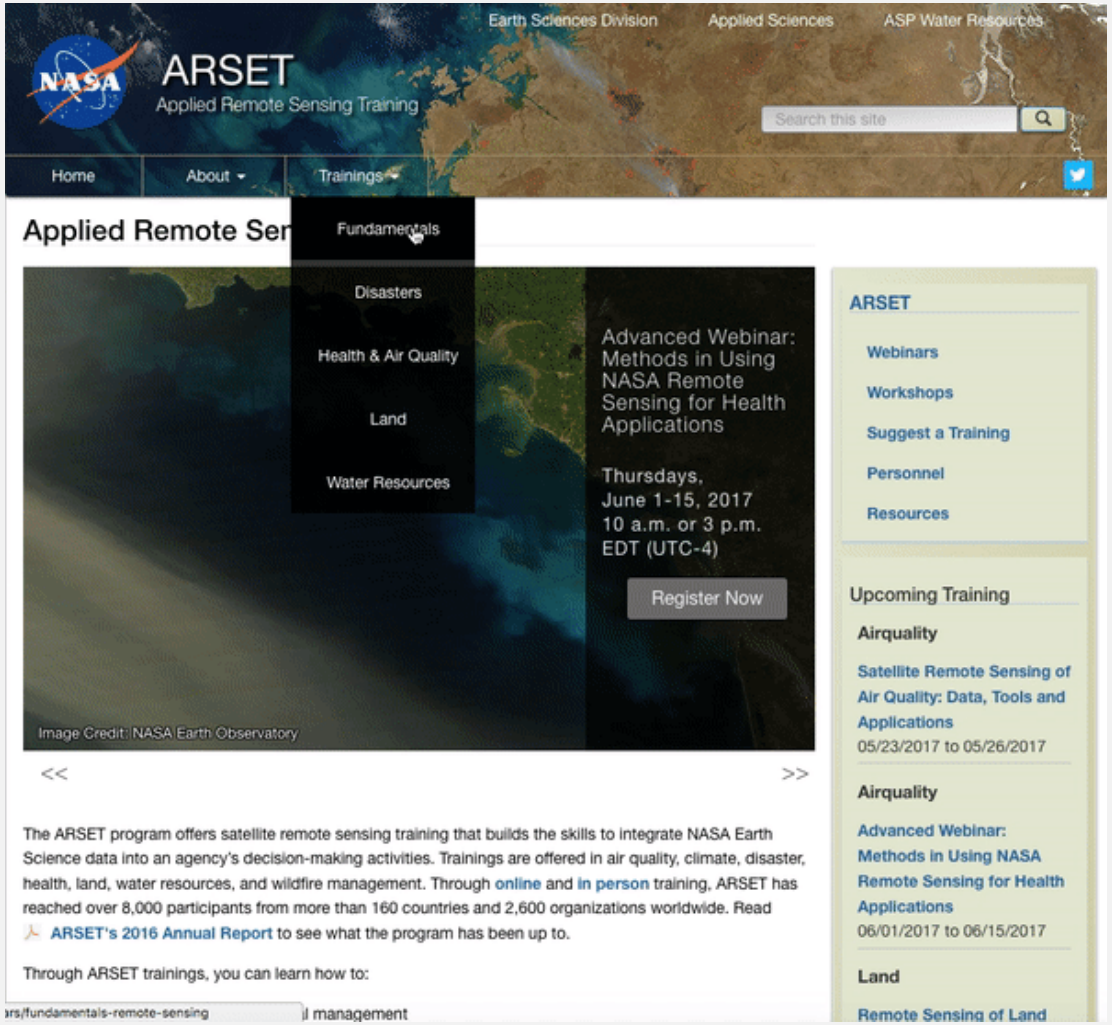
Advanced Webinar: Remote Sensing of Drought

July 12 – July 19, 2017

Trainers: Amber McCullum, Amita Mehta, and Cynthia Schmidt

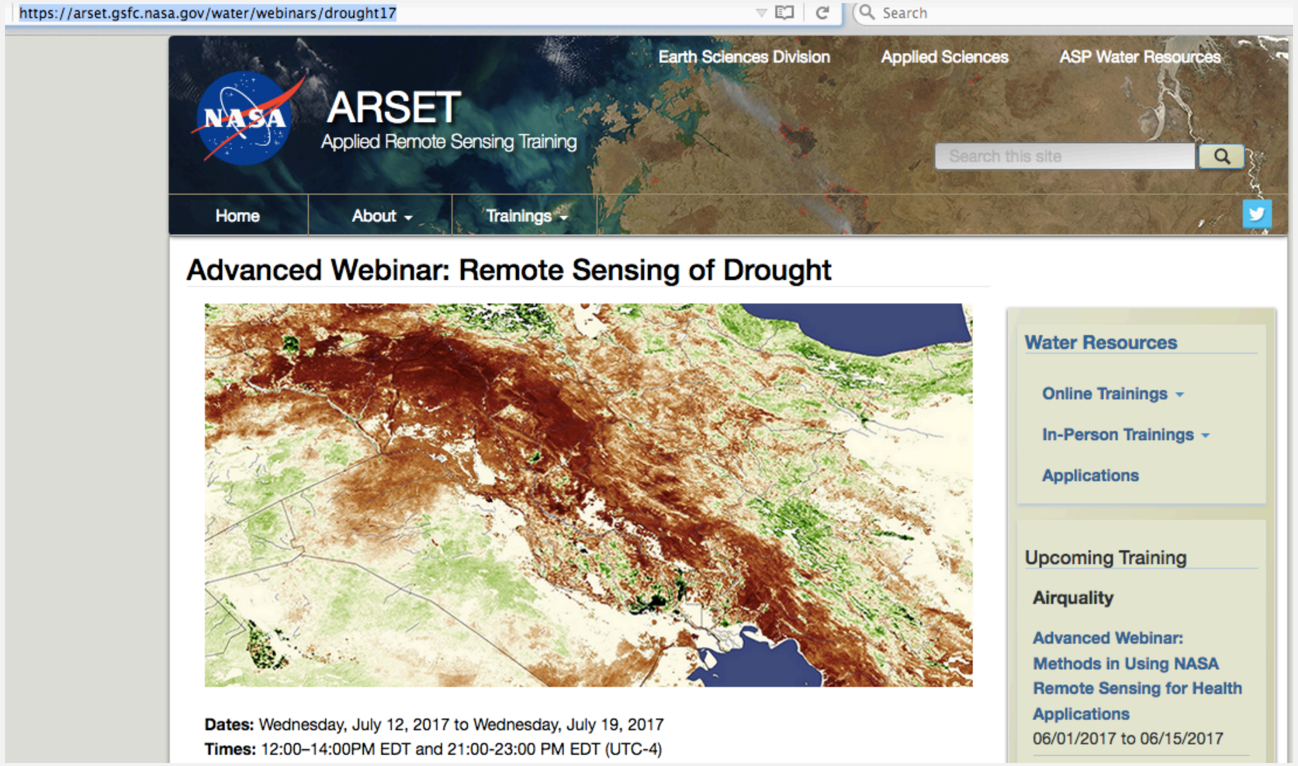
Prerequisites

- Fundamentals of Remote Sensing
  - Sessions 1, 2A, and 2B
  - On demand webinar, available anytime
  - http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing
- Download and install QGIS
  - https://www.qgis.org/en/site/forusers/download.html
  - Open software to ensure it is working properly



Course Material

Webinar recordings, presentations, in class exercises, and homework are available at: http://arset.gsfc.nasa.gov/water/webinars/drought17/



Course Agenda:

Agenda.pdf

Remote Sensing-Based Drought Monitoring

July 12, 2017

This session will include an overview of drought classification, an introduction to web-based drought monitoring tools, a demonstration of drought data visualization tools, and end with an exercise for attendees to practice downloading data.

- View the Recording »
- Presentation Slides (English) »

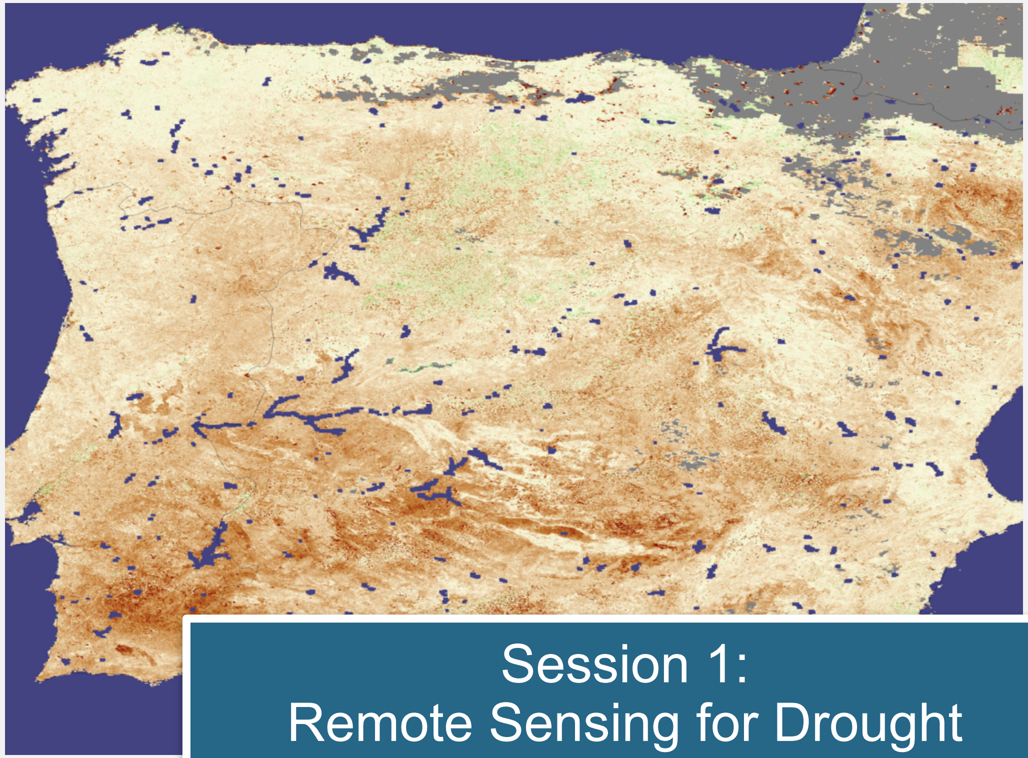
Drought Monitoring Analysis and Application

July 19, 2017

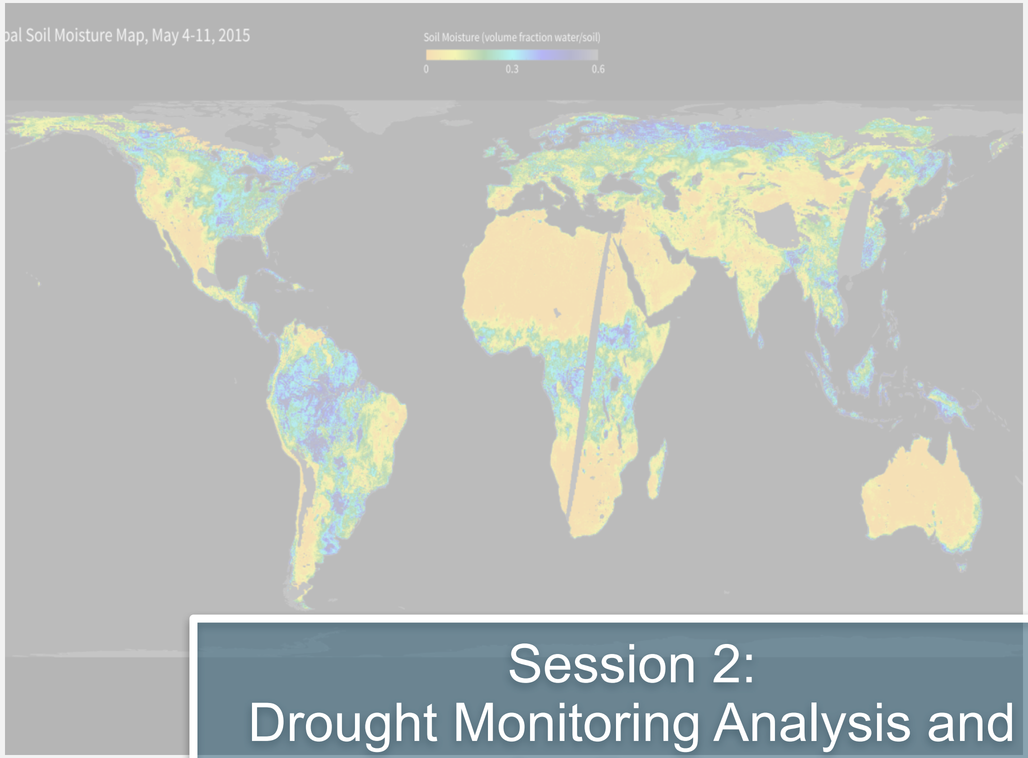
This session will include a demonstration of soil moisture, groundwater, NDVI, and evapotranspiration (ET) data access and visualization, and will use a case study (California) exercise to demonstrate how participants can analyze drought conditions. Background will also be provided for a case study (northern Africa) to be used by participants to independently conduct their own analysis.

- View the Recording »
- Presentation Slides (English) »
- Homework Assignment »

Course Outline



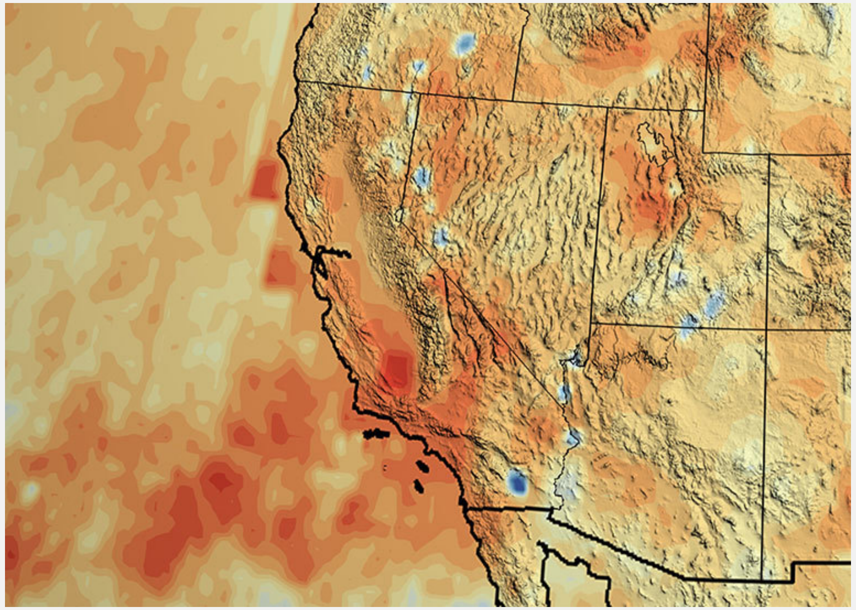
Session 1:
Remote Sensing for Drought Monitoring

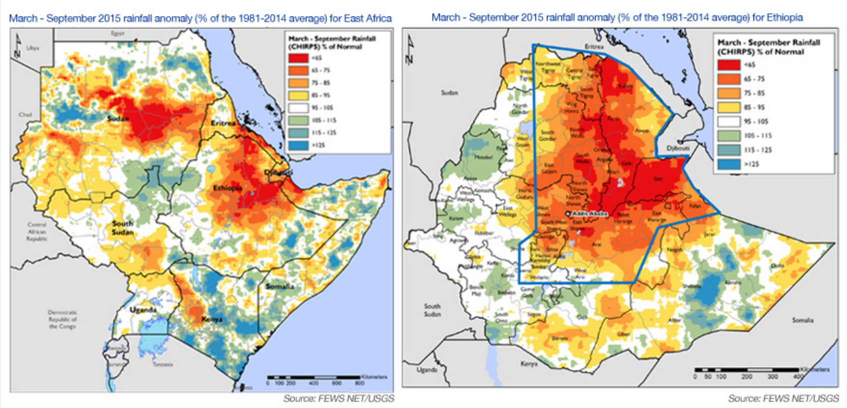


Session 2:
Drought Monitoring Analysis and Application

Session 1 Agenda

- Overview of Drought Classification
- Remote Sensing Data for Drought Monitoring
- Drought Monitoring with Precipitation
- Drought Monitoring with Vegetation
- Introduction and Demonstration of Web-Based Drought Monitoring Tools
- Exercise: Downloading Data for Drought Monitoring
  - Precipitation
  - NDVI





California's precipitation deficit from 2012-2014 via TRMM (NASA Global Climate Change) (Top); Famine Early Warning System rainfall anomalies, 2015 (right).

Overview of Drought Classification

Types of Droughts

All droughts originate from “below normal” precipitation

- Meteorological Drought
- Agricultural Drought
- Hydrological Drought
- Socioeconomic Drought

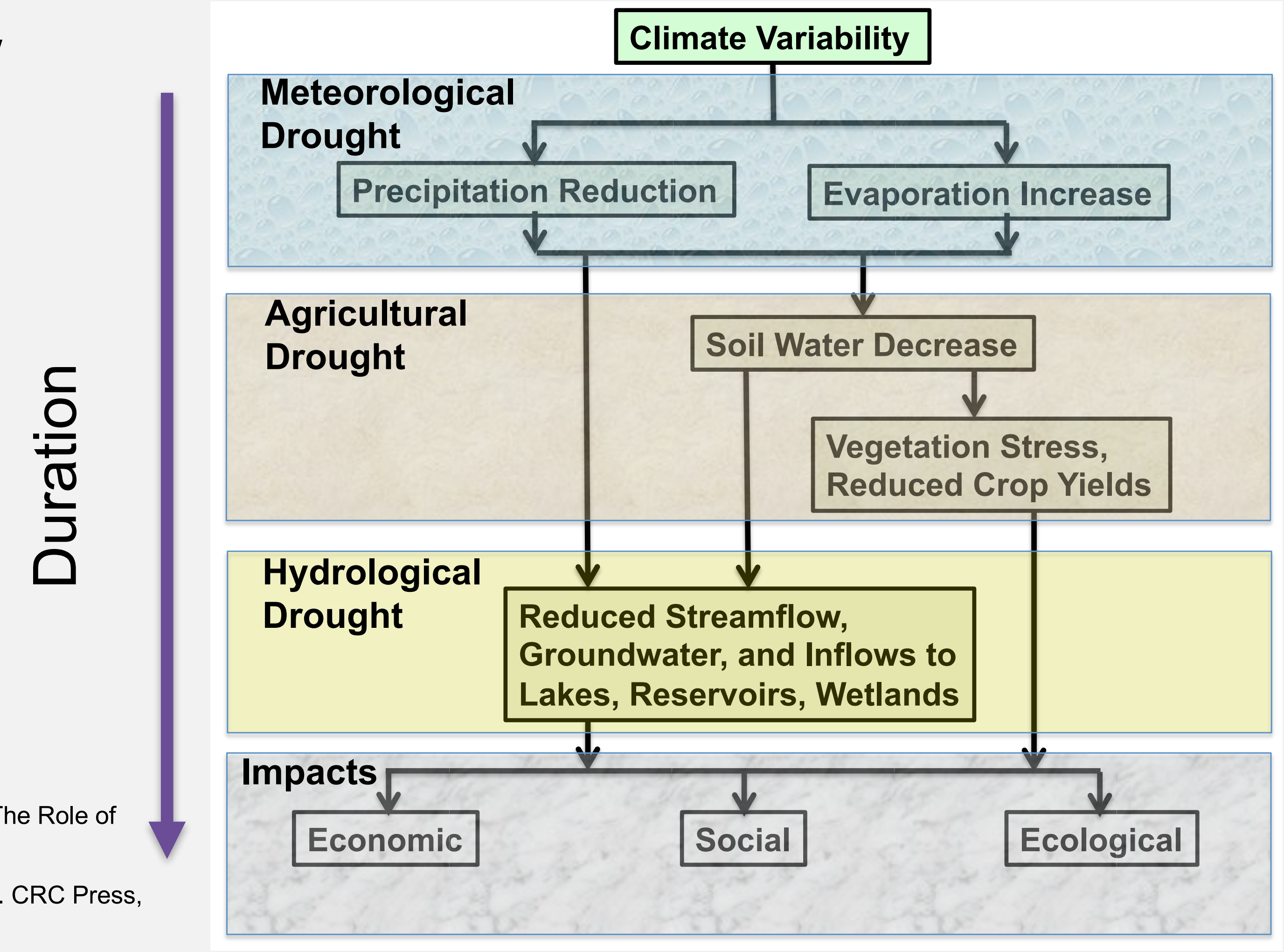
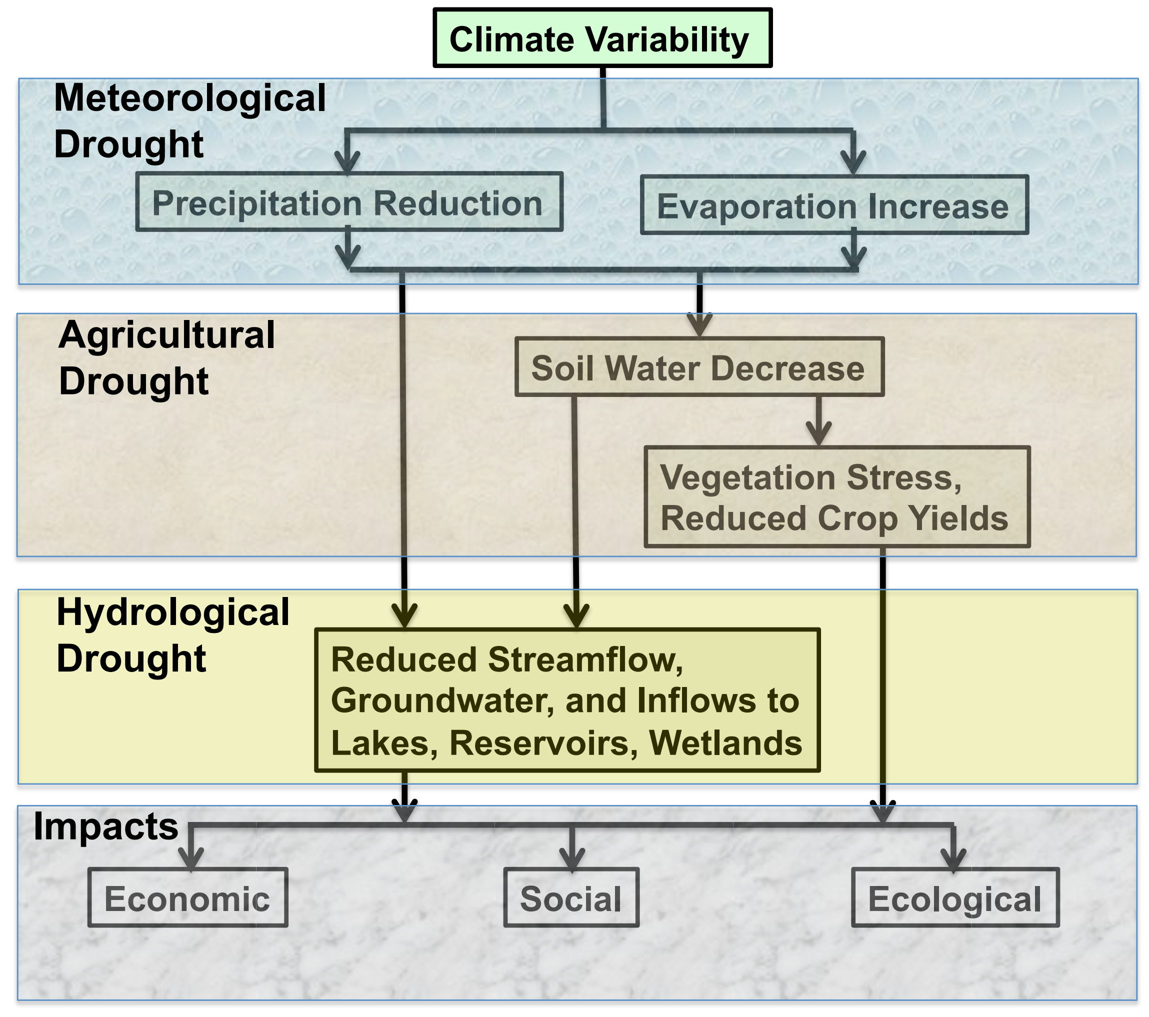


Image Credit: National Drought Mitigation Center

Wilhite, D.A.; and M.H. Glantz. 1985. Understanding the Drought Phenomenon: The Role of Definitions. *Water International* 10(3):111–120

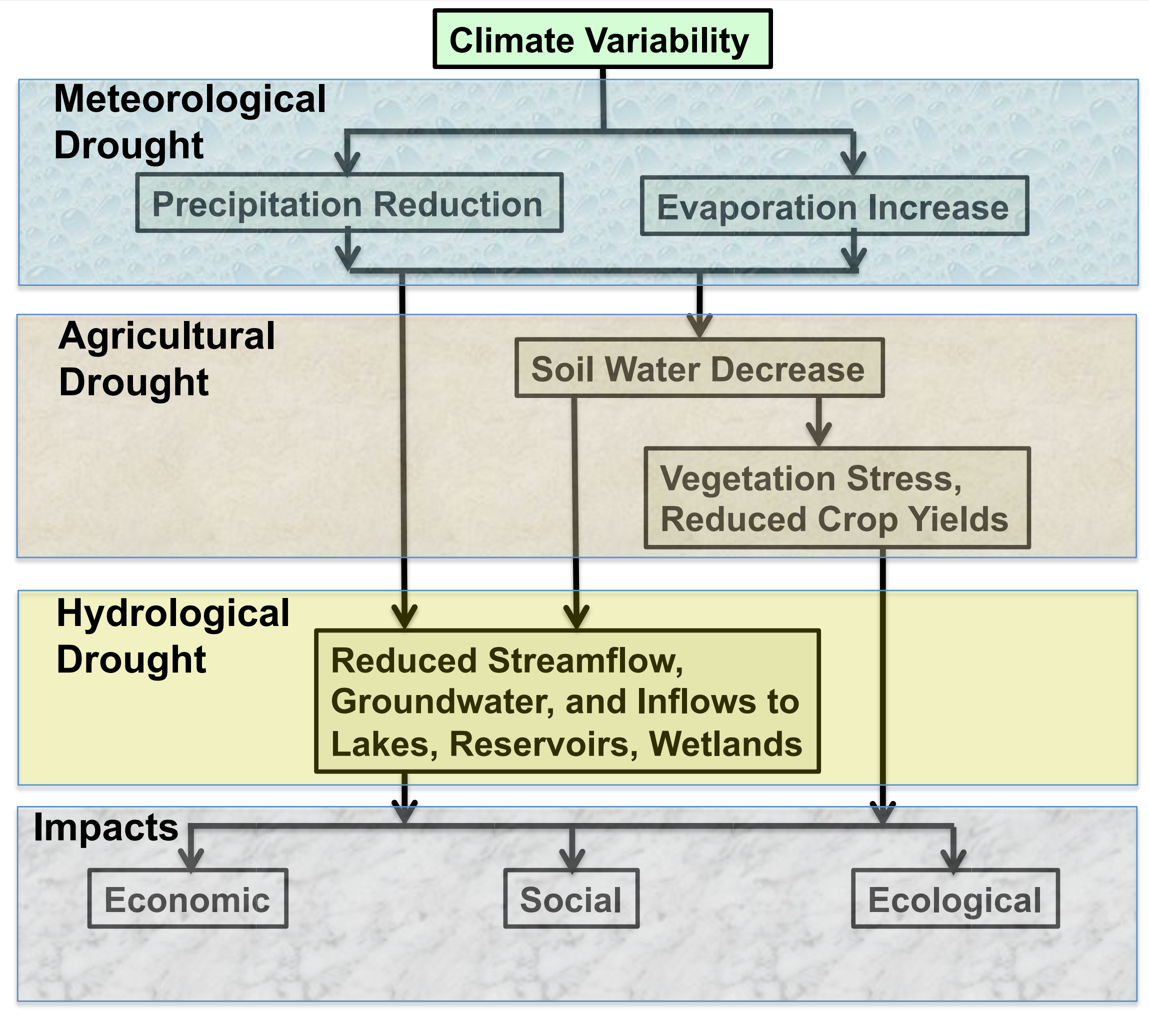
Figure: Mehta, V.M., 2017: Natural Decadal Climate Variability: Societal Impacts. CRC Press, Boca Raton, Florida, 326 pp.

Types of Droughts



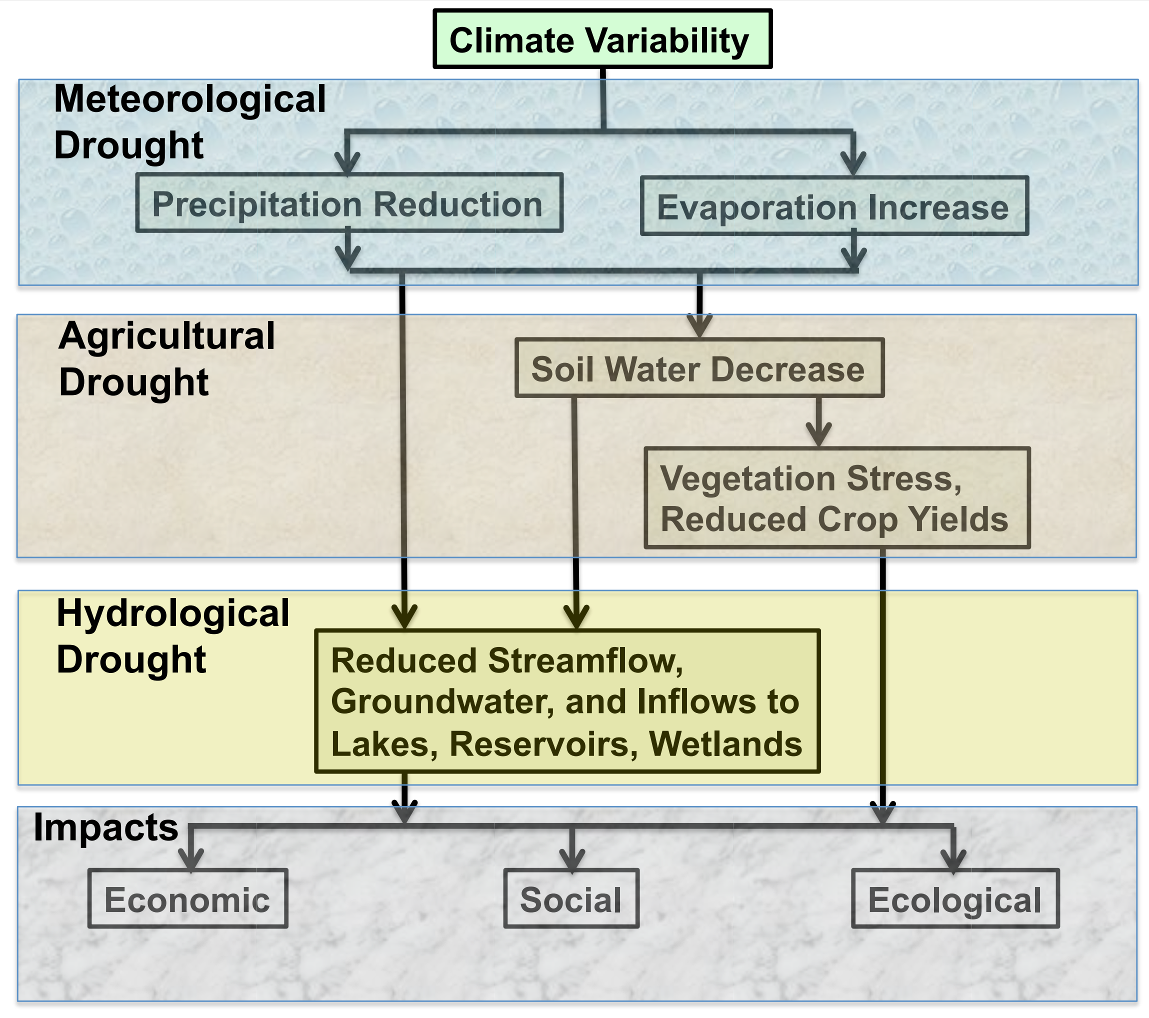
- Meteorological Drought
  - related to degree of dryness compared to ‘normal’ precipitation
  - region-specific and high spatial variability
- Agricultural Drought
  - related to various conditions like precipitation shortage, evapotranspiration and agricultural impact

Types of Droughts

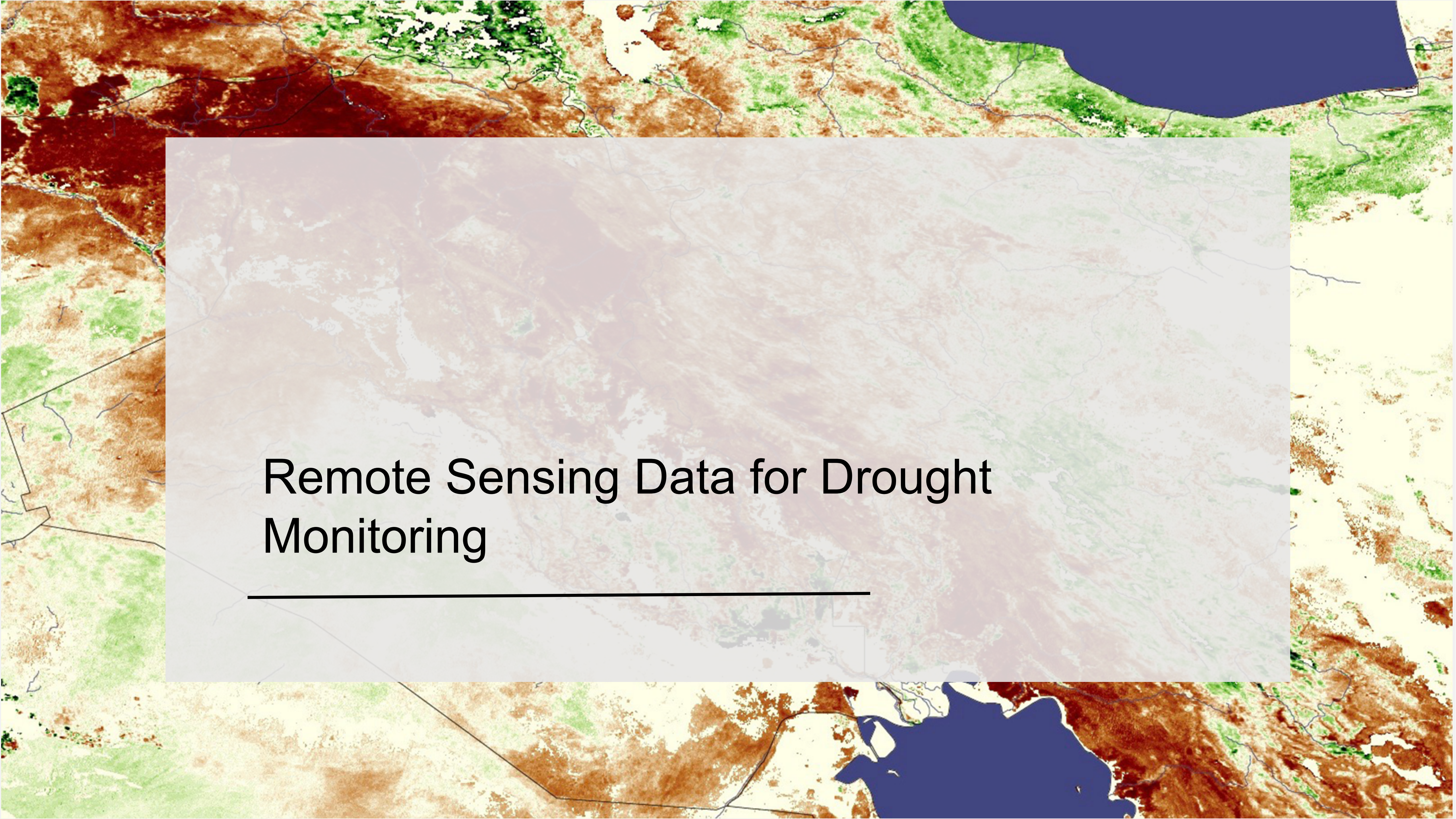


- Ecological Drought
  - prolonged and widespread deficit in naturally available water supplies that create multiple stresses across ecosystems
- Hydrological Drought
  - related to rain and snow shortfall
  - impact on surface and subsurface water supply
  - affects agricultural drought

Types of Droughts



- Socioeconomic Drought
  - related to supply and demand rates of goods and economy
  - affected by agricultural, ecological, and hydrological
  - social and economic changes



Remote Sensing Data for Drought Monitoring

NASA Satellites for Drought Monitoring

- Landsat: 07/1972 – present
- Tropical Rainfall Measuring Mission (TRMM): 11/1997 – 04/2015
- Global Precipitation Measurements (GPM): 02/2014 – present
- Terra: 12/1999 – present
- Aqua: 05/2002 – present
- Soil Moisture Active Passive (SMAP): 01/2015 – present
- Gravity Recovery and Climate Experiment (GRACE): 03/2002 – present

For detail information about the satellites and sensors see Session 2A and 2B on https://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing

NASA Remote Sensing Data Available for Drought Monitoring

Type of Drought	Parameters	Satellites
Meteorological Drought	Precipitation	TRMM, GPM
Agricultural Drought	Normalized Difference Vegetation Index (NDVI), Evapotranspiration	Landsat, Terra, Aqua
Hydrological Drought	Soil Moisture, Ground Water	SMAP, GRACE

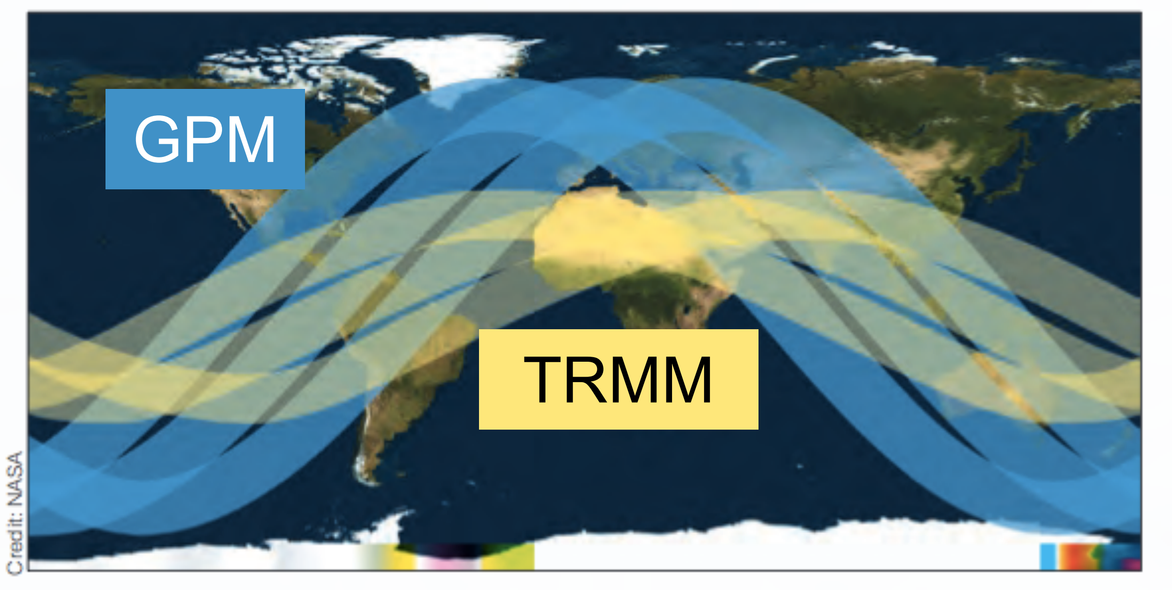
NASA Remote Sensing Data Available for Drought Monitoring

Type of Drought	Parameters	Satellites
Meteorological Drought	**Precipitation**	TRMM, GPM
Agricultural Drought	**Normalized Difference Vegetation Index (NDVI)**, Evapotranspiration	Landsat, Terra, Aqua
Hydrological Drought	Soil Moisture, Ground Water	SMAP, GRACE

- We will analyze precipitation and NDVI data for drought monitoring
- We will learn to visualize soil moisture, evapotranspiration, and ground water anomalies for drought monitoring

Precipitation from TRMM and GPM

- TRMM and GPM: NASA & JAXA (Japanese Space Agency) Joint Missions
- Both in non-polar, low-inclination orbits
- TRMM covered global tropics, between 50°S – 50°N
- GPM covers global tropics, between 65°S – 65°N
- TRMM Sensors:
  – **TMI, PR, VIRS**, LIS, CERES
- GPM Sensors:
  – GMI, DPR

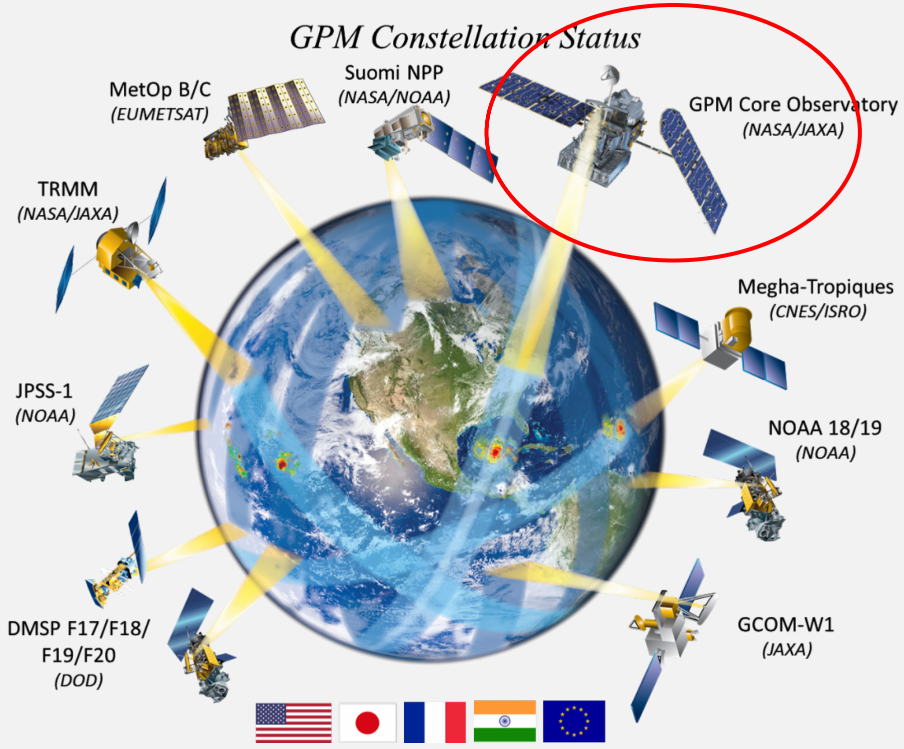


- TRMM: Nov 27, 1997 – Apr 15, 2015
- GPM: Feb 27, 2014 - present

Multi-Satellite Algorithms for TRMM and GPM

http://pmm.nasa.gov/science/precipitation-algorithms/

- TRMM and GPM Core satellites are used to calibrate microwave observations from a constellation of satellites
- These multi-satellite algorithms allow improved spatial and temporal coverage of precipitation data and are widely used for applications
  - TRMM Multi-satellite Precipitation Analysis (TMPA)
  - Integrated Multi-satellitE Retrievals for GPM (IMERG)



References:

Huffman, G.J., R.F. Adler, D.T. Bolvin, G. Gu, E.J. Nelkin, K.P. Bowman, E.F. Stocker, D.B. Wolff, 2007: The TRMM Multi-satellite Precipitation Analysis: Quasi-Global, Multi-Year, Combined-Sensor Precipitation Estimates at Fine Scale. J. Hydrometeor., 8, 33-55. MERG_ATBD_V4.5.pdf

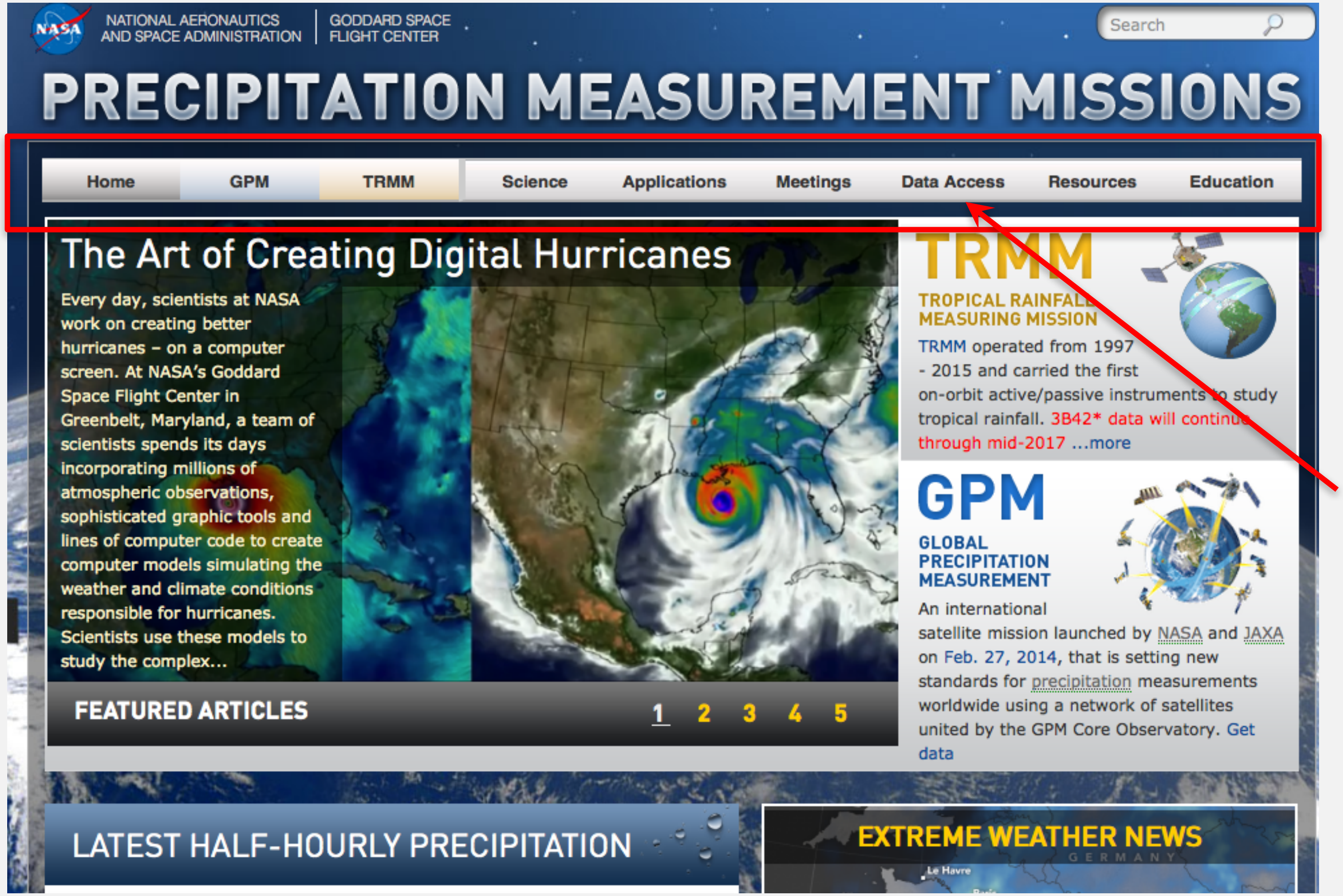
TMPA and IMERG

	TMPA	IMERG
Spatial Resolution	0.25° x 0.25°	0.1° x 0.1°
Spatial Coverage	Global, 50° S-50°N	Global, 60°S-60°N (will be extended from pole to pole)
Temporal Resolution	3 hours	30 minutes
Temporal Coverage	1/1998 – Present	3/1/2014 – Present

- Since April 8, 2015, TRMM climatological calibration is used to generate TMPA
- TMPA is available for more than 17 years and is used for drought monitoring
- TMPA and IMERG combined data will be available in early 2018 at IMERG data resolution

TRMM and GPM Data

Precipitation Measurement Missions: http://pmm.nasa.gov/

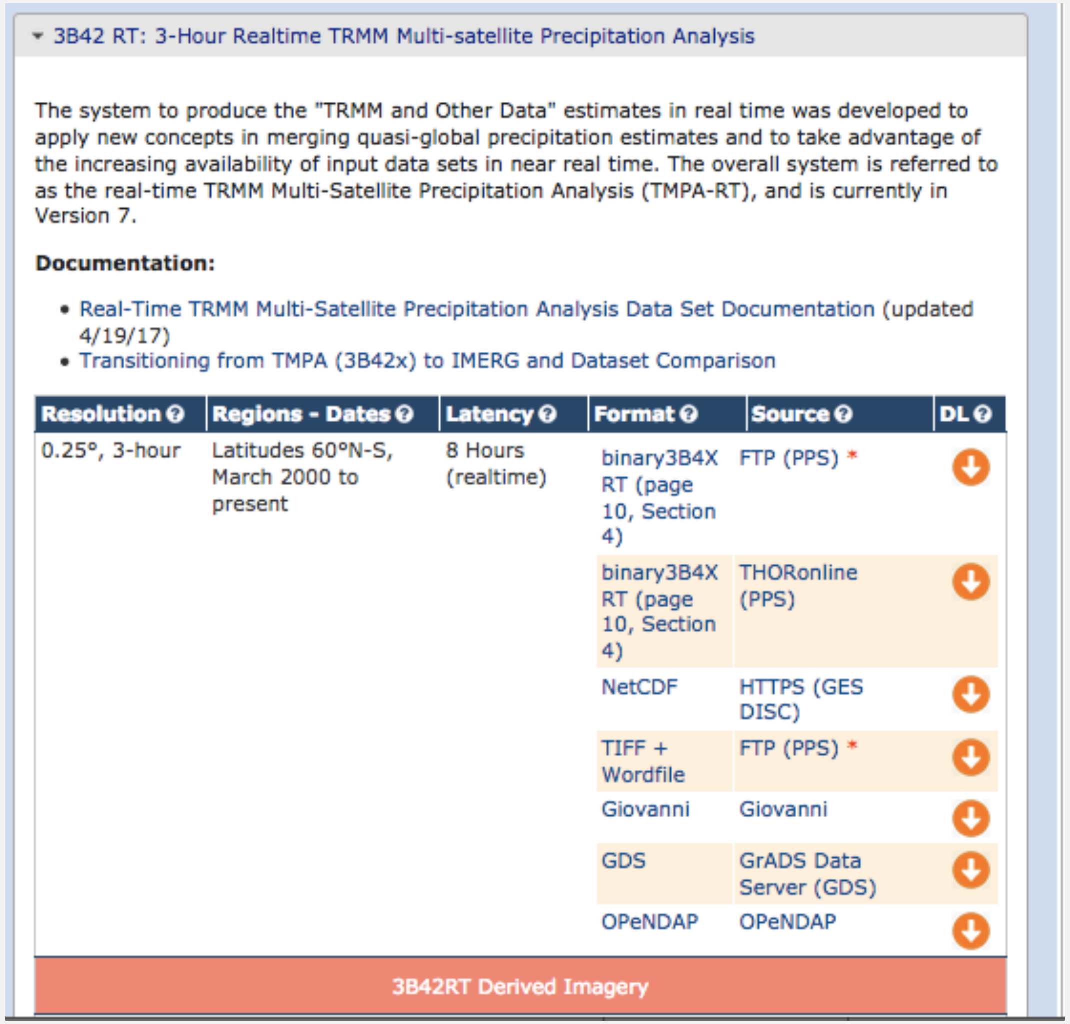


- Home to all information related to TRMM and GPM
- Links to Level-1 to Level-3 data via multiple web-based tools

TMPA Data

http://pmm.nasa.gov/data-access/downloads/trmm/

- Multiple web tools for data download
- We will use Giovanni to download TMPA monthly precipitation data for drought monitoring
  - http://giovanni.gsfc.nasa.gov/giovanni



3B42 RT: 3-Hour Realtime TRMM Multi-satellite Precipitation Analysis

The system to produce the "TRMM and Other Data" estimates in real time was developed to apply new concepts in merging quasi-global precipitation estimates and to take advantage of the increasing availability of input data sets in near real time. The overall system is referred to as the real-time TRMM Multi-Satellite Precipitation Analysis (TMPA-RT), and is currently in Version 7.

Documentation:

- Real-Time TRMM Multi-Satellite Precipitation Analysis Data Set Documentation (updated 4/19/17)
- Transitioning from TMPA (3B42x) to IMERG and Dataset Comparison

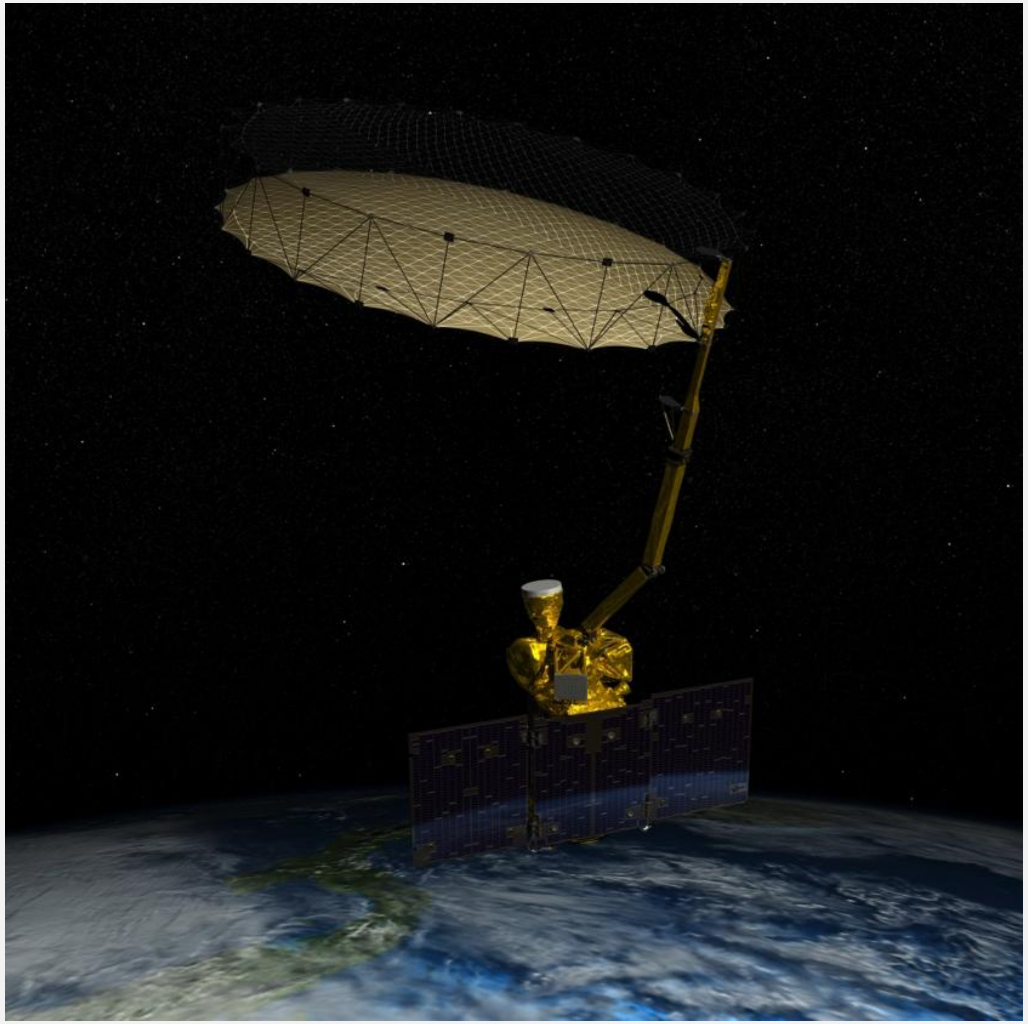
Resolution	Regions - Dates	Latency	Format	Source	DL
0.25°, 3-hour	Latitudes 60°N-S, March 2000 to present	8 Hours (realtime)	binary3B4XRT (page 10, Section 4)	FTP (PPS) *	
			binary3B4XRT (page 10, Section 4)	THORonline (PPS)	
			NetCDF	HTTPS (GES DISC)	
			TIFF + Wordfile	FTP (PPS) *	
			Giovanni	Giovanni	
			GDS	GrADS Data Server (GDS)	
			OPeNDAP	OPeNDAP	

3B42RT Derived Imagery

Soil Moisture Active Passive (SMAP) Mission

http://smap.jpl.nasa.gov/

- January 31, 2015 - present
- Polar orbit
- Global coverage every 2-3 days
- Swath width: 1,000 km
- SMAP Sensors:
  - Microwave Radiometer
  - Microwave Radar
    - currently unavailable

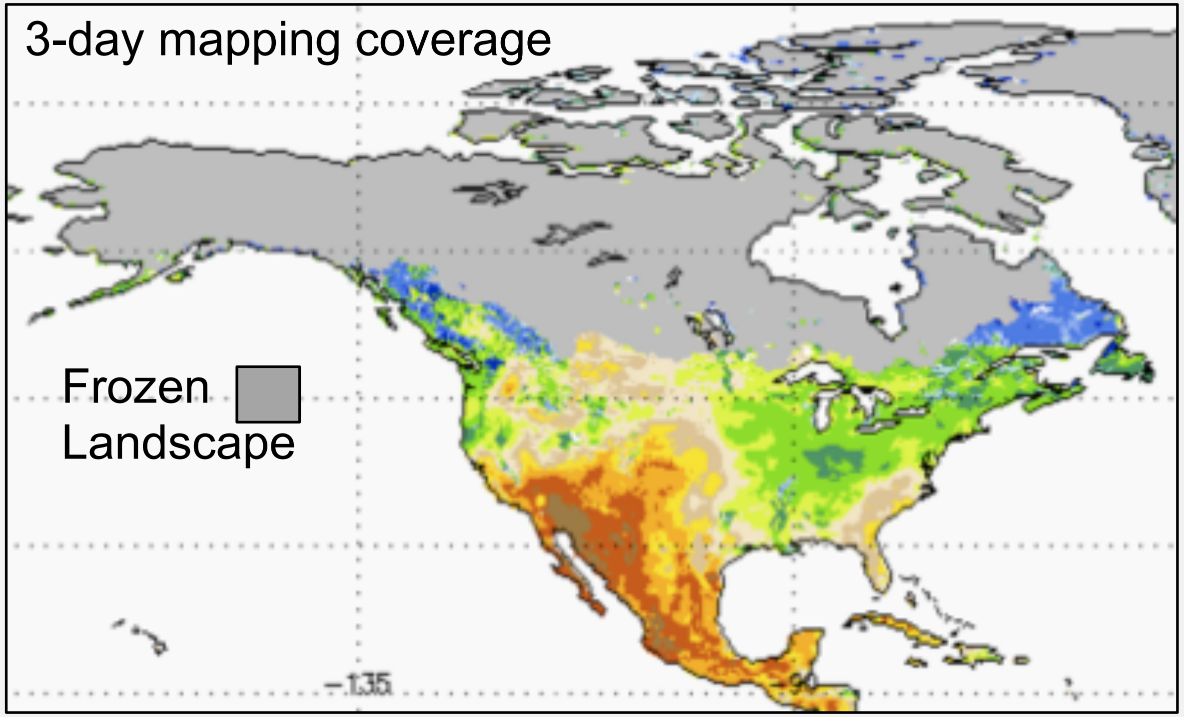


SMAP Microwave Data

http://smap.jpl.nasa.gov/data/

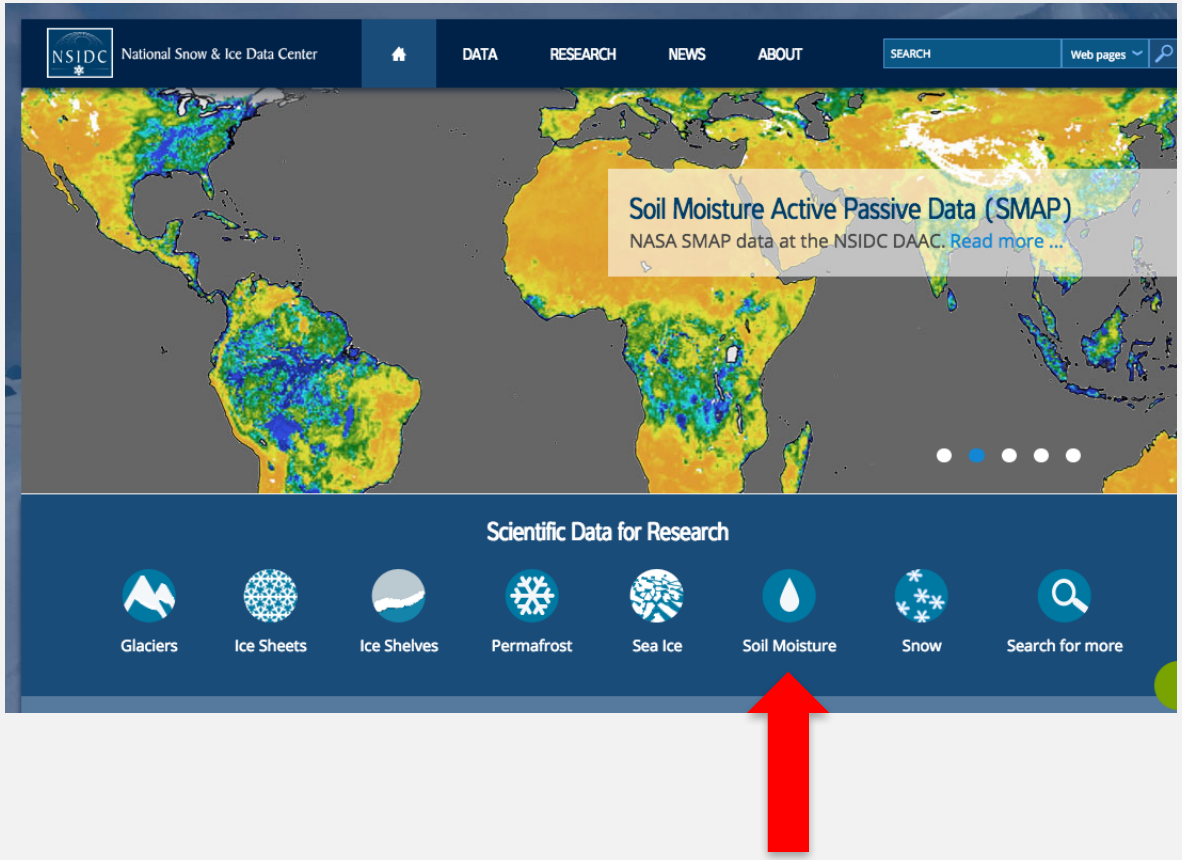
- Radiometer-based soil moisture (L2_SM-P)
  - Resolution: 36 km
  - 3 day global coverage
- Root Zone Soil Moisture (SMAP L4_SM)
  - SMAP observations assimilated in a land surface model
  - Resolution: 9 km
  - 3 hourly & 7 day coverage

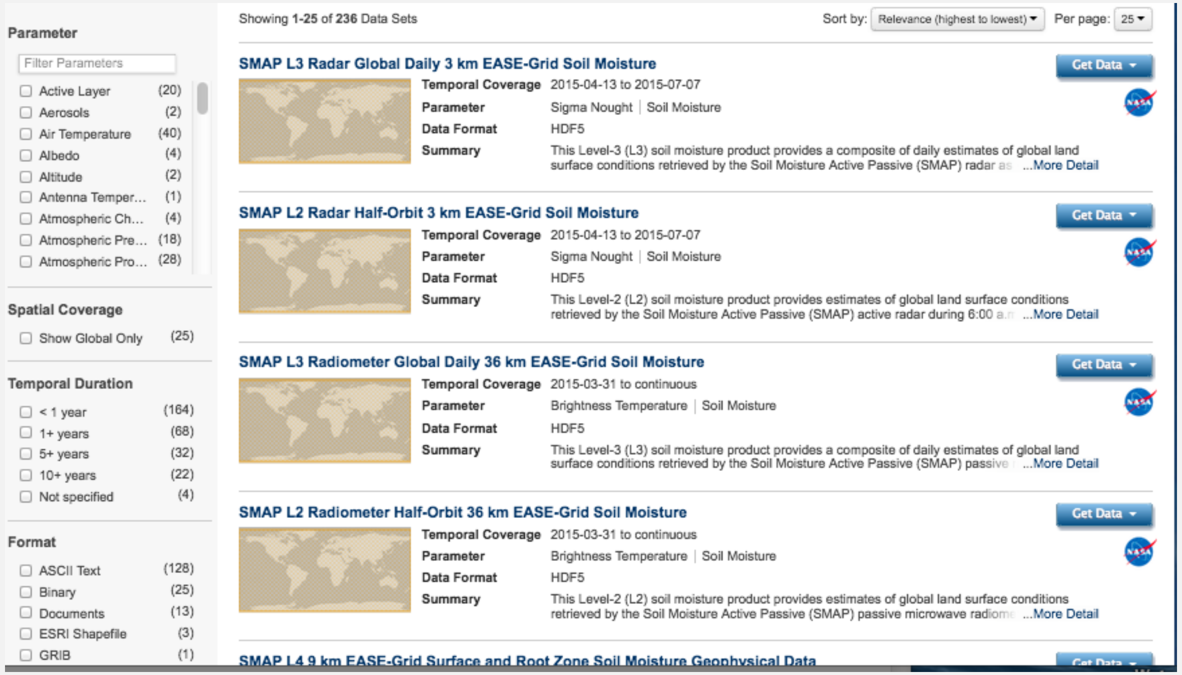
- measures the moisture in the top 5 cm of soil



Access to SMAP Data: National Snow & Ice Data Center

http://nsidc.org/data/search/#keywords=soil+moisture/

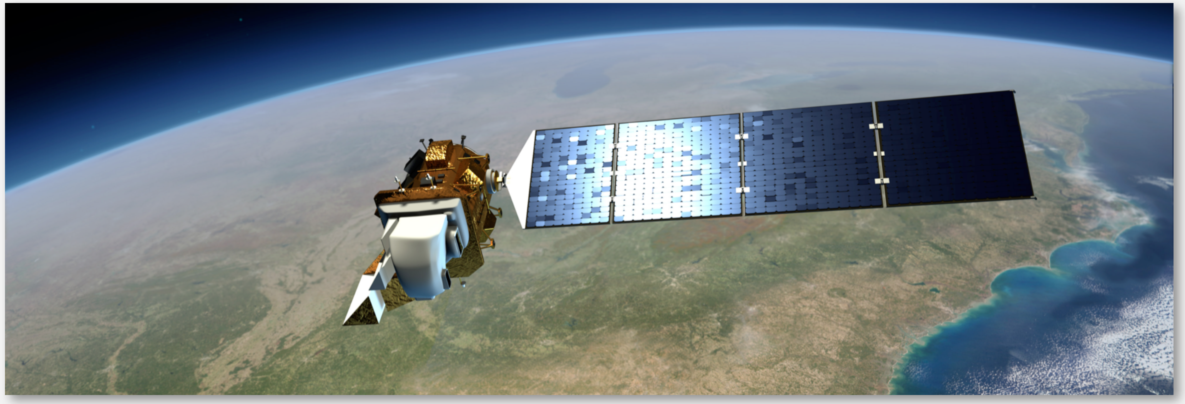


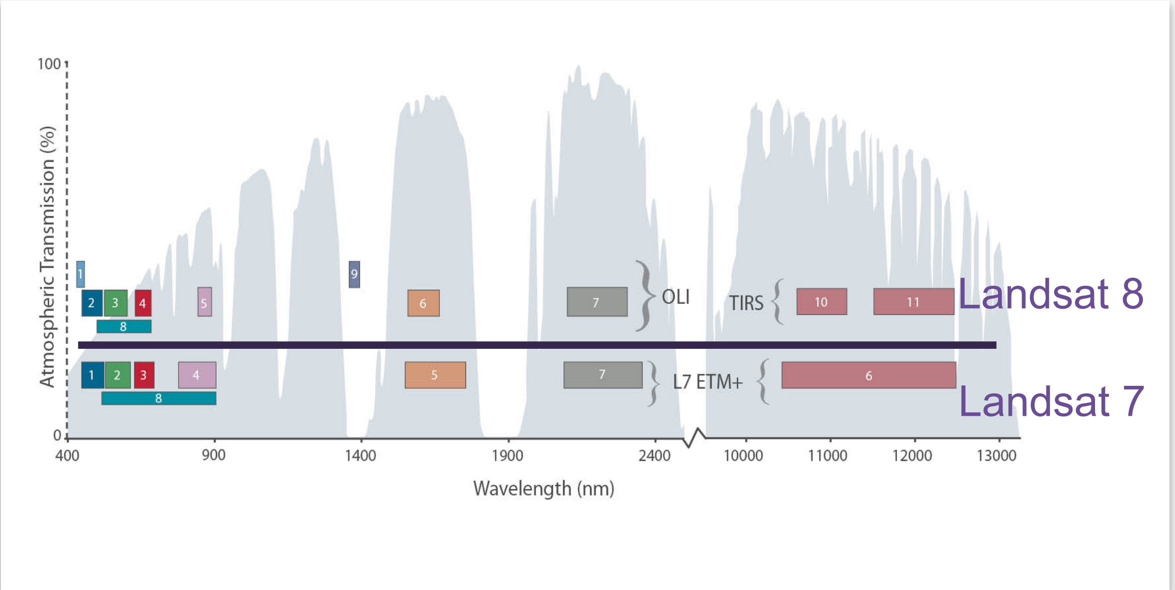


Level 2 to Level 4 data

Landsat Overview

- First Landsat launched in 1972
- Landsat 8 launched in 2013
- NASA created and launched
  – USGS maintains data
- Passive sensor: obtains values of reflectance from Earth's surface
- 30 meter pixels, 15 meter panchromatic band
- Entire image of the Earth every 16 days



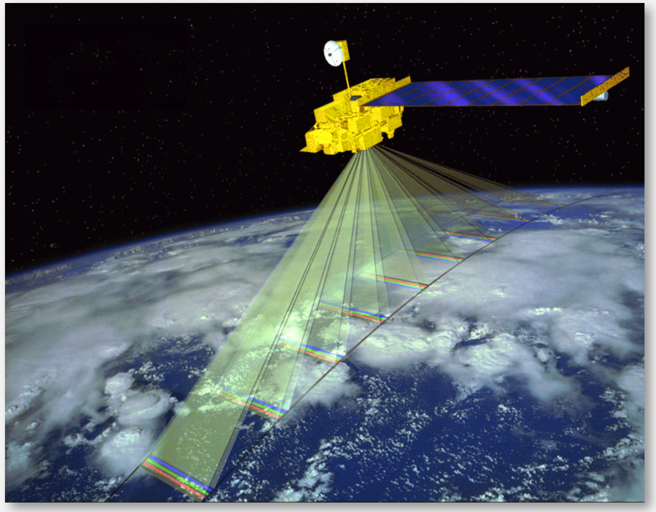


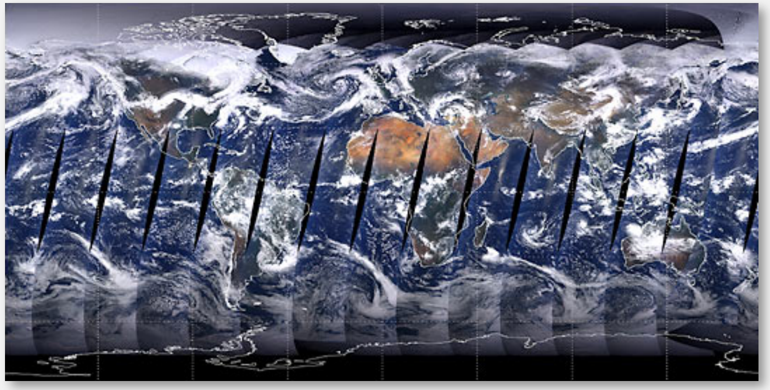
Landsat Bands for NDVI

Wavelengths	Landsat 8 Bands	Landsat 4,5, 7 Bands
Coastal aerosol	Band 1	
Blue	Band 2	Band 1
Green	Band 3	Band 2
Red	Band 4	Band 3
Near Infrared (NIR)	Band 5	Band 4
Shortwave Infrared (SWIR) 1	Band 6	Band 5
Shortwave Infrared (SWIR) 2	Band 7	Band 7
Panchromatic	Band 8	Band 8 (L7)
Cirrus	Band 9	
Thermal Infrared 1	Band 10	Band 6
Thermal Infrared 2	Band 11	

MODIS Overview

- Spatial Resolution
  – 250 m, 500 m, 1 km
- Temporal Resolution
  – Daily, 8 day, 16 day, monthly, quarterly, yearly
  – 2000 – present
- Data Format
  – Hierarchal data format – Earth Observing System Format (HDF–EO8)
- Spectral Coverage
- 36 bands (major bands include red, blue, IR, NIR, MIR)
  – Bands 1-2: 250 m
  – Bands 3-7: 500 m
  – Bands 8-36: 1000 m





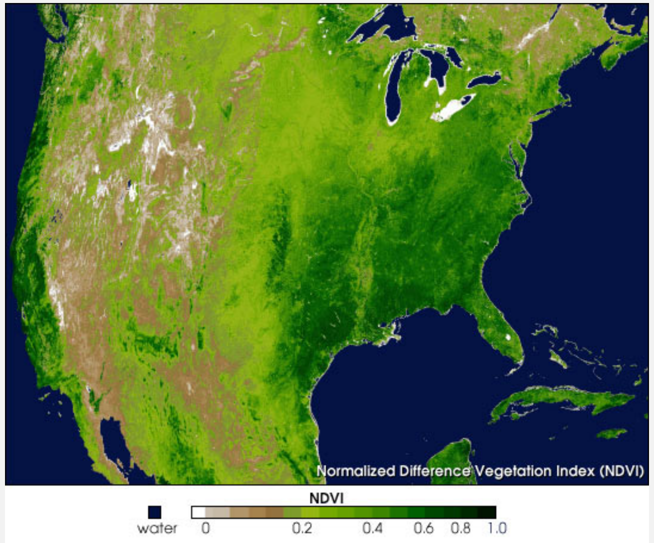
MODIS Land Products

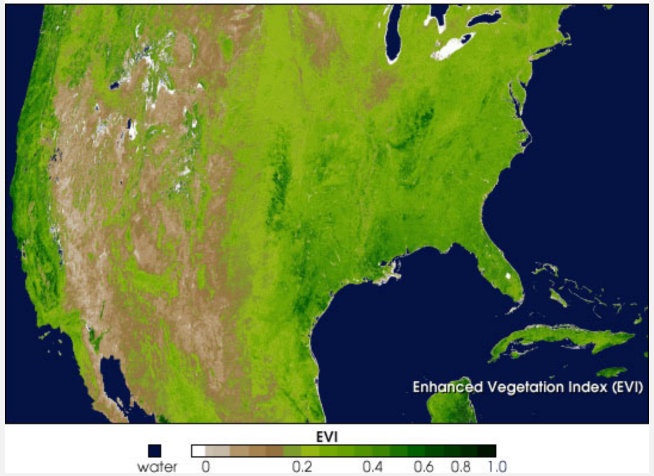
Short name

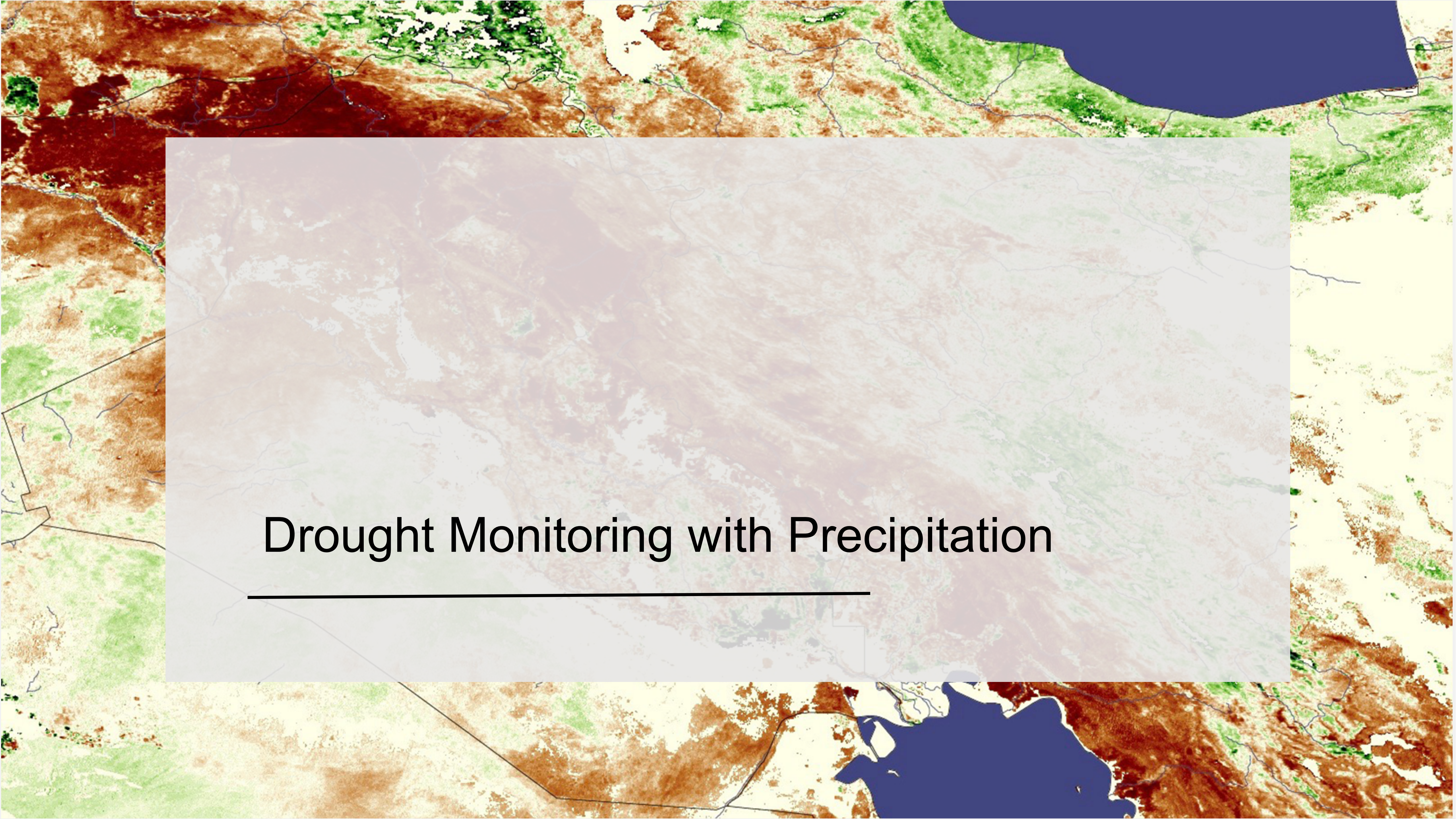
MODIS Name	Product Name	Spatial Resolution (m)	Temporal
MOD 09	Surface Reflectance	500	8-day
	Land Surface Temperature	1000	Daily, 8-day
MOD 12	Land Cover/Change	500	8-day, Yearly
MOD 13	Vegetation Indices	250-1000	16 day, monthly
MOD 14	Thermal Anomalies/Fire	1000	Daily, 8-day
MOD 15	Leaf Area Index/Fraction of Absorbed Photosynthetically Active Radiation (FPAR)	1000	4-day, 8-day
MOD 16	Evapotranspiration		
MOD 17	Primary Production	1000	8-day, yearly
MOD 43	Bidirectional reflectance distribution function (BRDF)/Albedo	500-1000	16-day
MOD 44	Vegetation Continuous Fields	250	yearly
MOD 45	Burned Area	500	monthly

MODIS Vegetation Indices Product Overview

- Vegetation Indices:
  - NDVI (Normalized Difference Vegetation Index)
    - 16 day, 250 meter spatial resolution as a gridded level 3 product
    - Used for characterizing land surface processes
    - Anomalies can be used to identify drought
  - EVI (Enhanced Vegetation Index)
    - Minimizes canopy background
    - Improvement in dense vegetation conditions







Drought Monitoring with Precipitation

Precipitation Anomalies as Drought Indicator

- Anomalies are a departure from the long-term climatological mean values and indicate dry or wet conditions compared to the climatological condition
- The figure shows accumulated precipitation anomalies (percent deficit in precipitation) map for the California between 2012 and 2014, based on TRMM data

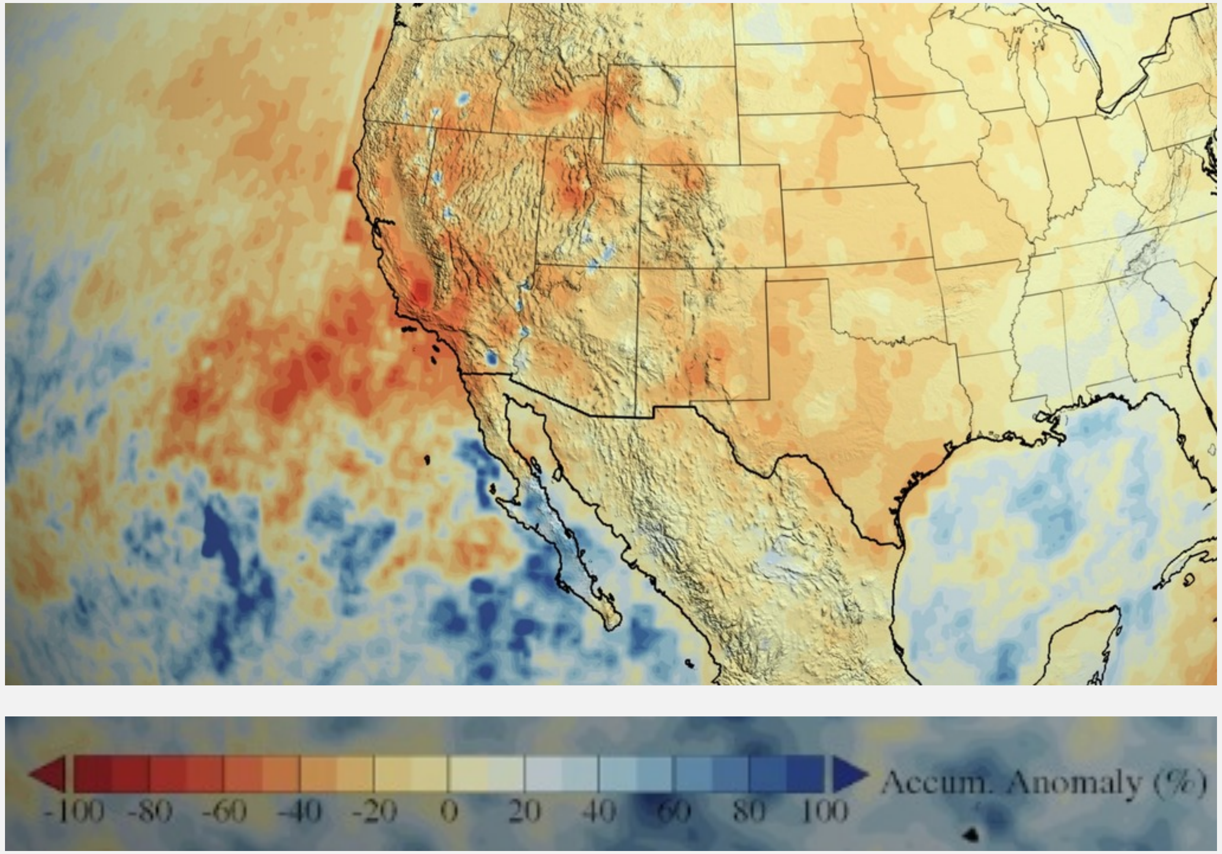
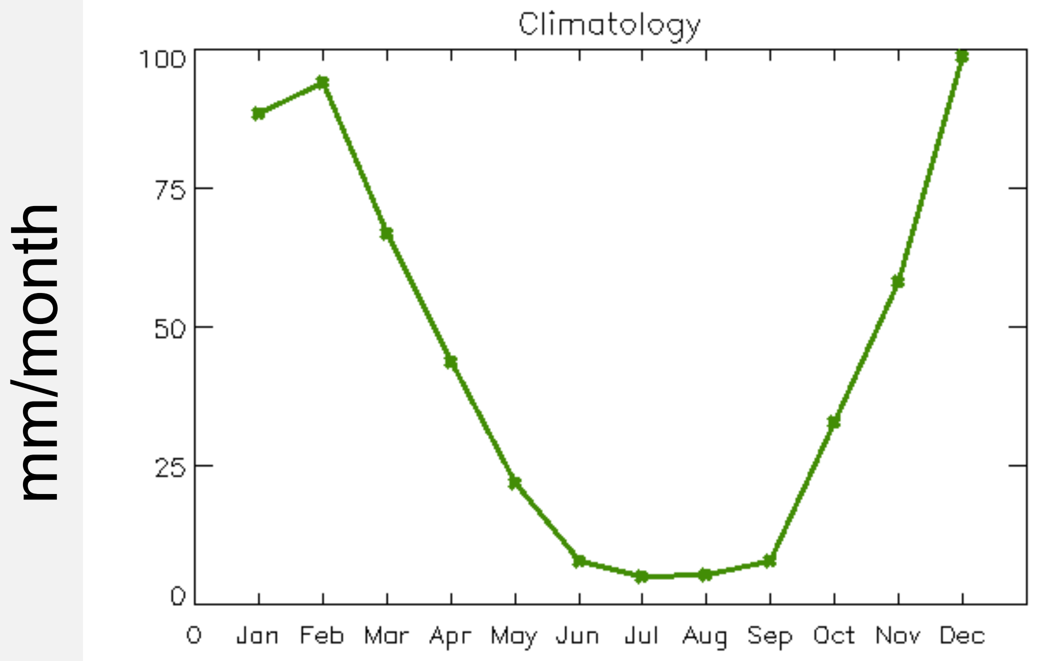


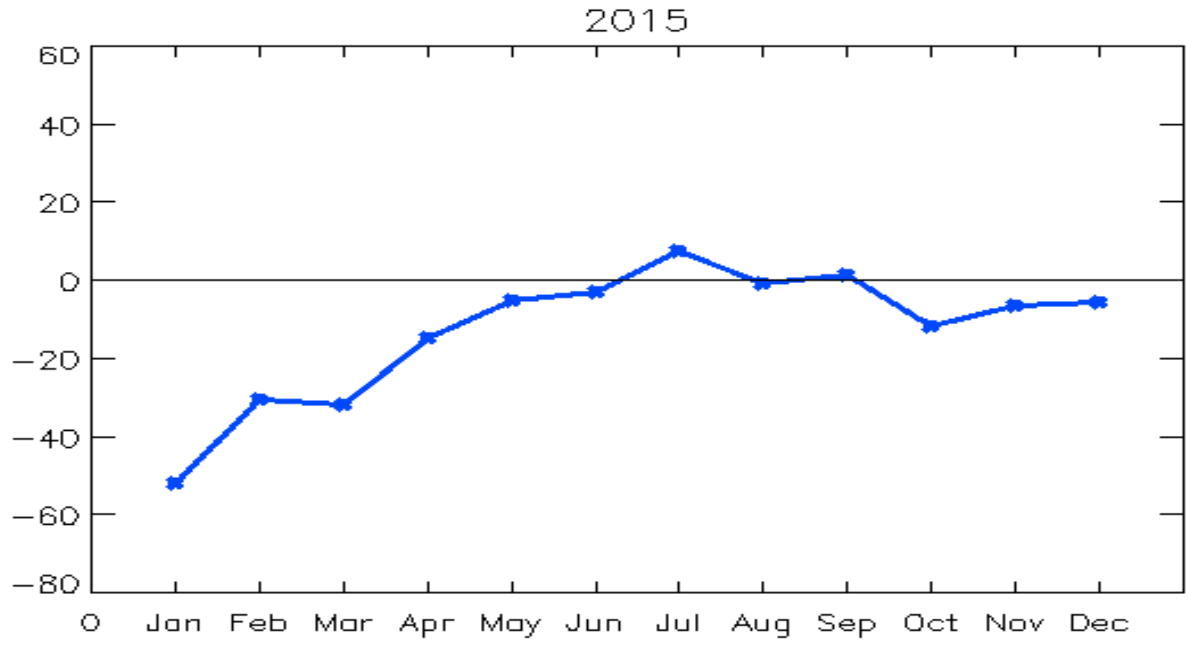
Image Credit: NASA Goddard Scientific Visualization Studio

TMPA Climatology and Anomalies Over California

Averaged over 1998-2016



Rainfall Deficit over California in 2015



Precipitation-Based Drought Indices

- Drought indices are mathematical representation of water deficit (and excess) compared to historical data
- Help decide when to start implementing water conservation or drought response measures
- Can be used to analyze drought frequency, severity, and duration for a given location and period

- Commonly used operational drought indices are:
  – Standardized Precipitation Index (SPI)
  – Palmer Drought Severity Index (PDSI)

Source: National Drought Mitigation Center; Image: Handbook of Drought Indicators & Indices

Standardized Precipitation Index (SPI)

http://www.cpc.ncep.noaa.gov/products/Drought/Monitoring/spi.shtml

- Primarily defined to characterize meteorological drought
- Mathematically, historical rainfall data at any location fitted with gamma distribution represent cumulative probability function
- If a rainfall event is a low probability on the cumulative probability function, it is indicative of a drought event
- The SPI values can be interpreted as the number of standard deviations by which the observed rainfall anomaly deviates from the long-term mean

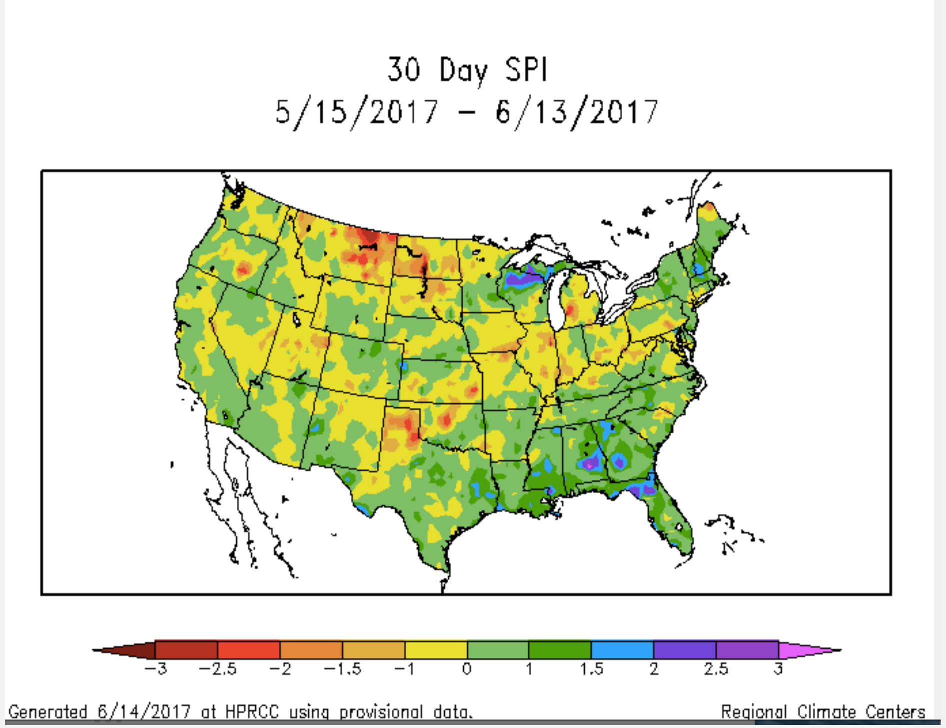


Image Credit: HPRCC ACIS Climate Map
http://hprcc.unl.edu/maps.php?map=ACISClimateMaps#

Text Source: NCAR/UCAR Climate Data Guide; Guttman, N. B., 1999: Accepting the Standardized Precipitation Index: A calculation algorithm. J. Amer. Water Resour. Assoc.., 35(2), 311-322.

Standardized Precipitation Index (SPI)

http://drought.unl.edu/MonitoringTools/ClimateDivisionSPI/Interpretation.aspx

SPI averaged over different time period indicate severity and duration of drought

- 3-month SPI: reflects short- to medium-term moisture conditions
- 6-month SPI: reflects medium-term precipitation conditions, including seasonal precipitation patterns
- 9-month SPI: reflects medium-term drought that potentially affects agriculture
- 12-month and longer SPI: represents drought that potentially affects streamflow, reservoir levels

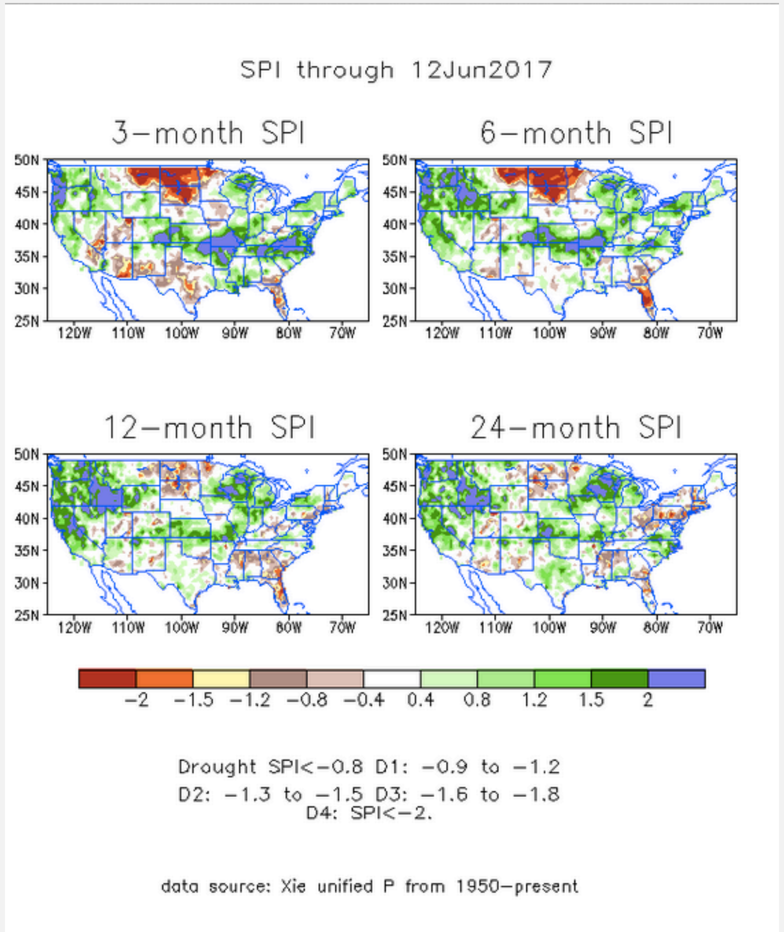


Image Credit: CPC/NOAA

SPI: Strengths and Limitations

http://climatedataguide.ucar.edu/climate-data/standardized-precipitation-index-spi

Strengths

- Easy to calculate based on precipitation
- Different time scales indicate duration of drought and impacts on hydrology and agricultural
- Program to calculate SPI is available from National Drought Mitigation Center
  - http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx
  - (requires learning)

Limitations

- Based on precipitation (water supply) alone and does not take into account temperature or evapotranspiration (water depletion)
- Values depends on the climatological precipitation used
- Precipitation intensity of rain or how it affects runoff, streamflow, and water availability for a given region

Palmer Drought Severity Index (PDSI)

http://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi

- An index for evaluating the severity and frequency of prolonged periods of abnormally dry or wet conditions
- Uses **temperature** and **precipitation** data and a physical water balance model to estimate relative dryness
- A standardized index that goes from -10 (dry) to +10 (wet)

PDSI(m)=PDSI{m-1+[Z(m)/3-0.103 PDSI(m-1)}

- m = month index
- Z(m) = moisture anomaly index (based on a water balance model)

- Learn more:
  - http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/palmer_drought/wpdanote.shtml

Palmer, W. C., 1965: Meteorological drought. Research Paper 45, U.S. Dept. of Commerce, 58 pp.

Dai, A., K. E. Trenberth, and T. Qian, 2004: A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. J. Hydrometeorology, 5, 1117-1130.

PDSI: Strengths and Limitations

http://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi

Strengths

- More effective for long-term drought
- Takes account of surface air temperature and potential evapotranspiration, not just precipitation
- Takes prior month's condition into account

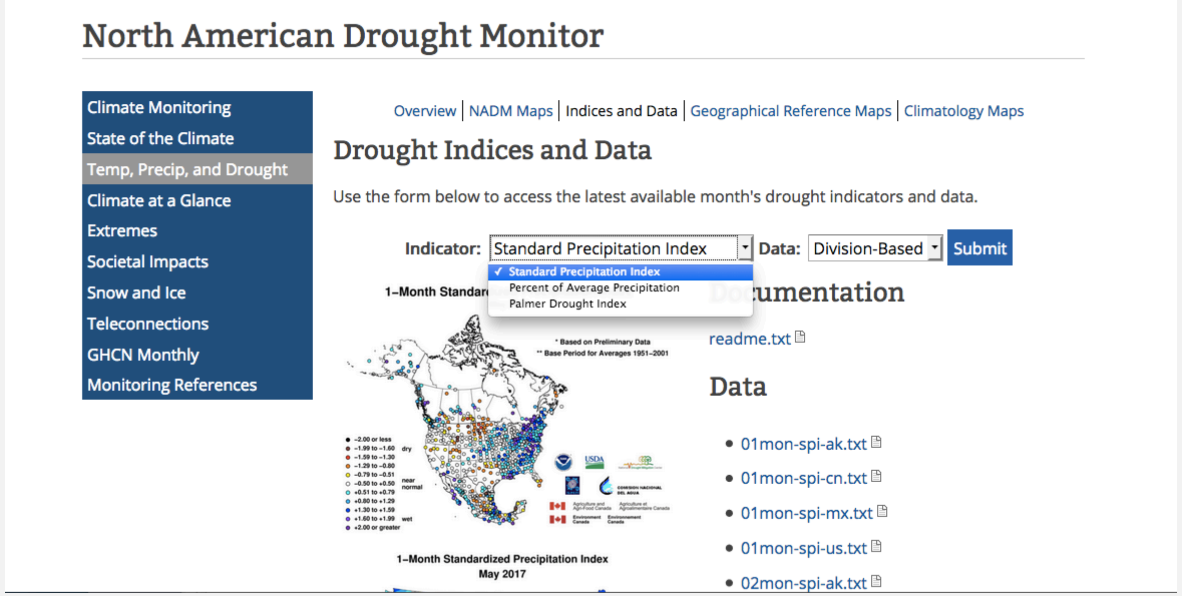
Limitations

- Lacks multi-time scale features
- Not comparable across regions, but self-calibrating PDSI can alleviate this issue
- Assumes that precipitation is immediately available (delayed runoff due to snow or ice not considered)

SPI and PDSI from NOAA

http://www.ncdc.noaa.gov/temp-and-precip/drought/nadm/indices

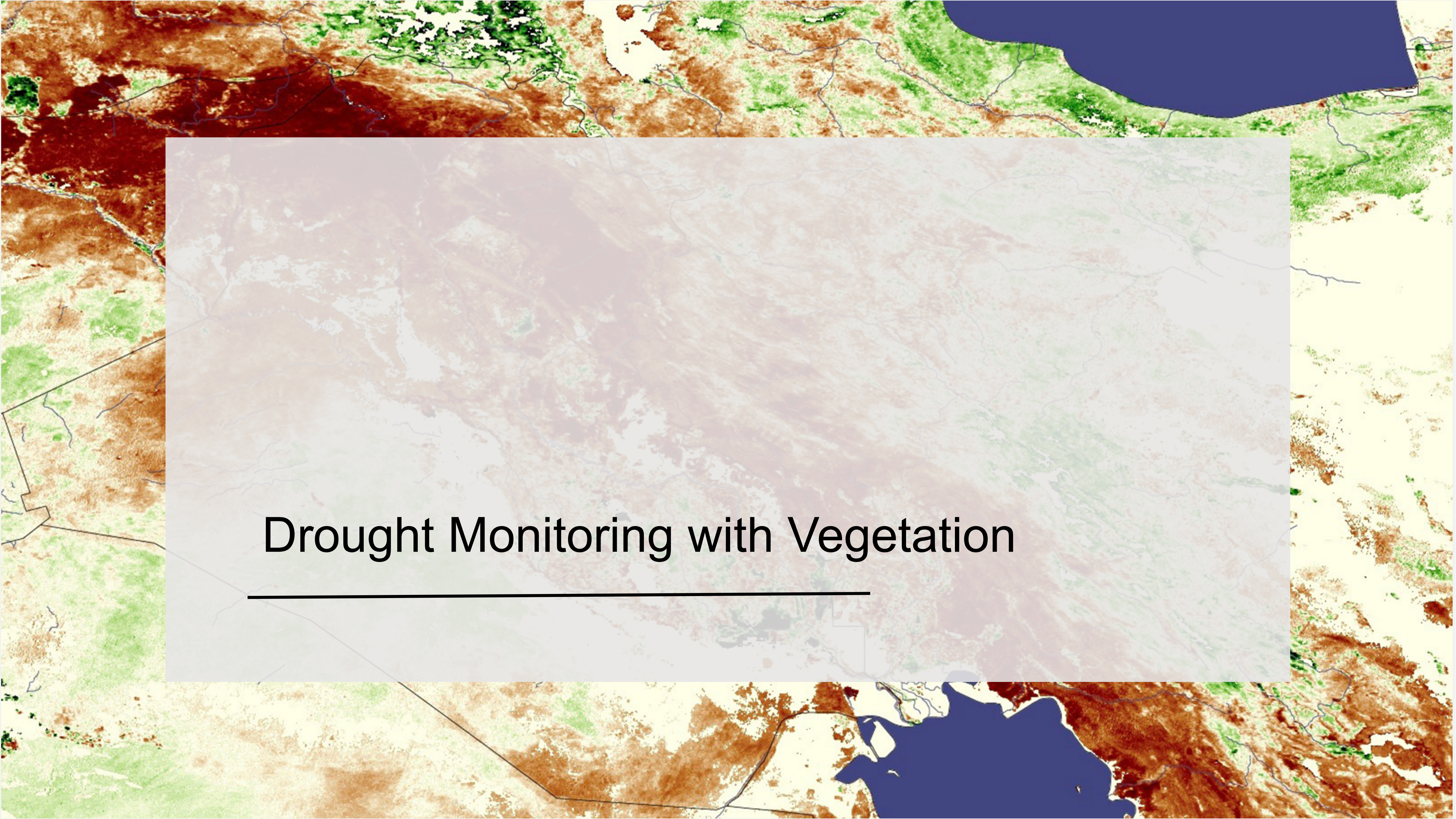
- SPI and PDSI based on surface data are available from North American Drought Monitor
- Though remote sensing-based precipitation record is relatively short, TRMM-TMPA has shown to be useful for getting regional SPI (De Jesus et al., 2016) and global PDSI (Sheffield et al, 2012)



De Jesús, A., J. Agustín Breña-Naranjo, A. Pedrozo-Acuña, and V. Hugo Alcocer Yamanaka, 2016:The Use of TRMM 3B42 Product for Drought Monitoring in Mexico, Water, 8, doi:10.3390/w8080325

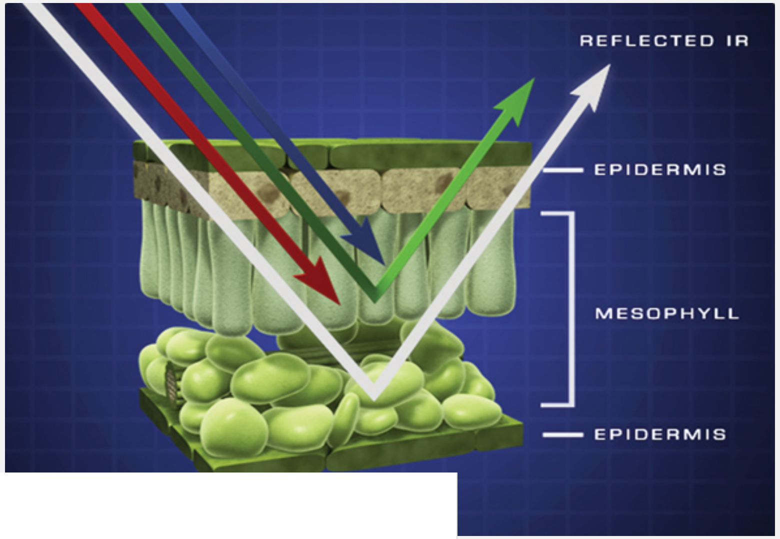
Sheffield, J., G. Goteti, and E. F. Wood, 2006: Development of a 50-yr high-resolution global dataset of meteorological forcings for land surface modeling, J. Climate, 19 (13), 3088-3111

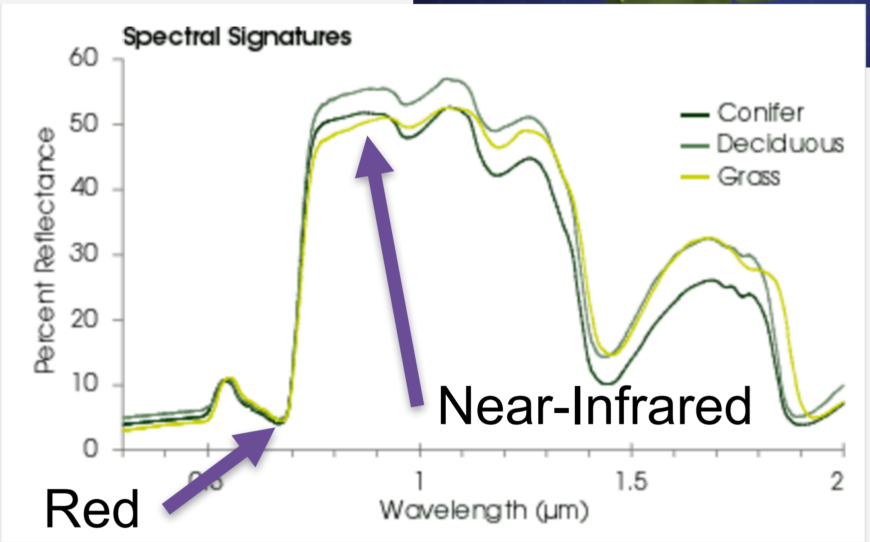
Drought Monitoring with Vegetation



What is NDVI?

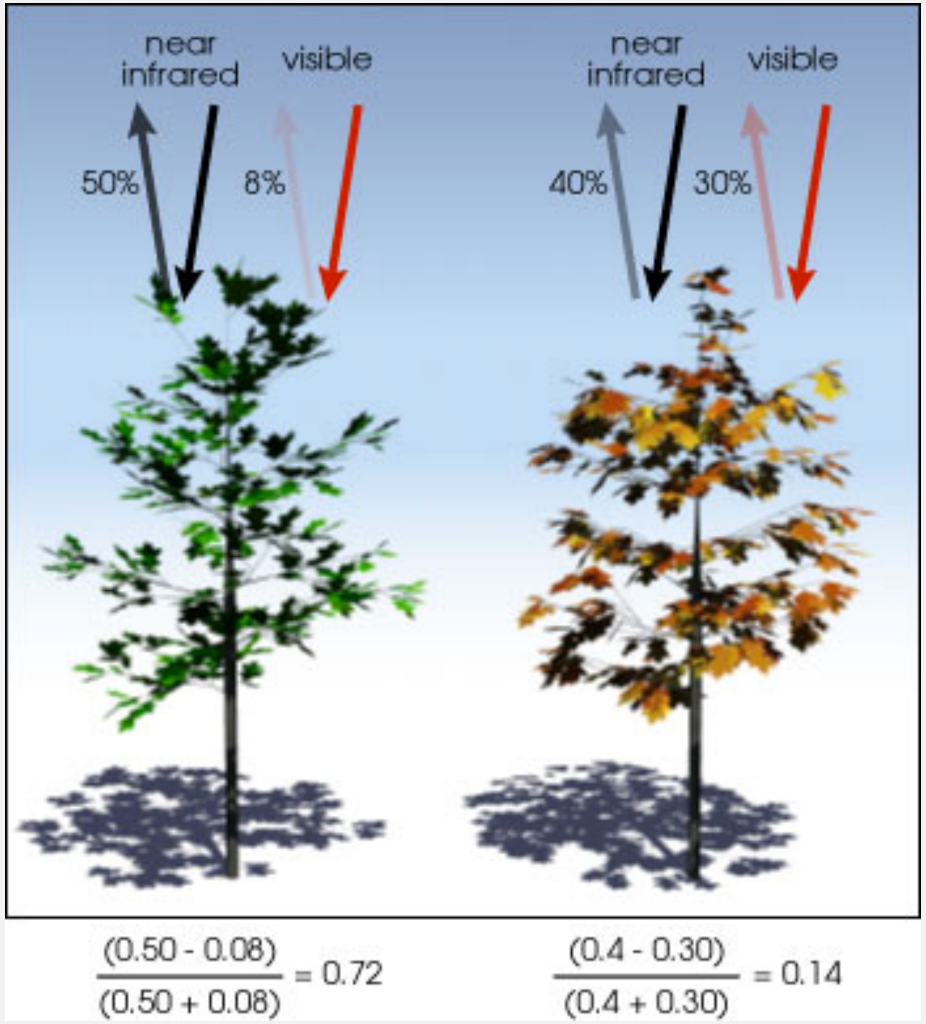
- Normalized Difference Vegetation Index
  - Based on the relationship between red and near-infrared wavelengths
  - Chlorophyll strongly absorbs visible (red)
  - Plant structure strongly reflects near-infrared





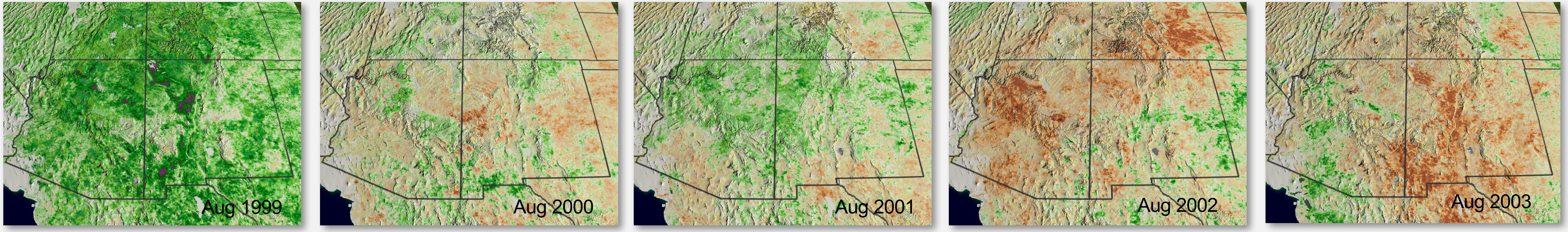
What is NDVI?

- NDVI formula: $\dfrac{\text{Near Infrared - Red}}{\text{Near Infrared + Red}}$
- Values range from -1.0 to 1.0
  - Negative values to 0 mean no green leaves
  - Values close to 1 indicate the highest possible density of green leaves



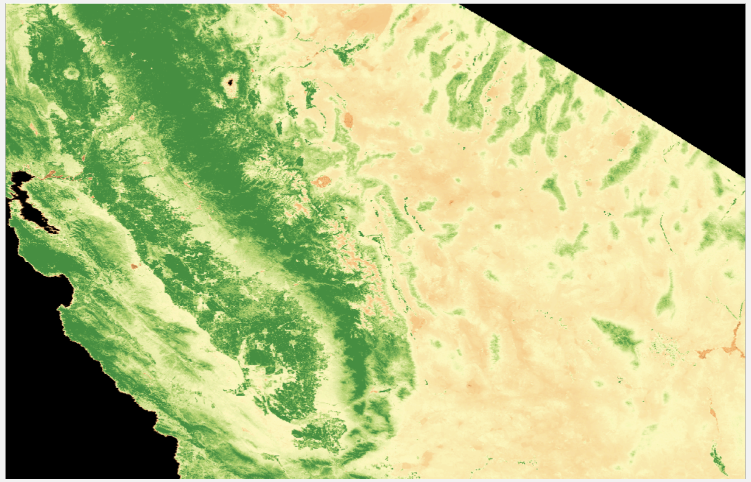
NDVI Anomalies

- Departure of NDVI from the long-term average, normalized by long-term variability
- Generated by subtracting the long-term mean from the current value for that month of the year for each grid cell.
- Indicates if vegetation greenness at a particular location is typical for that period or if the vegetation is more or less green



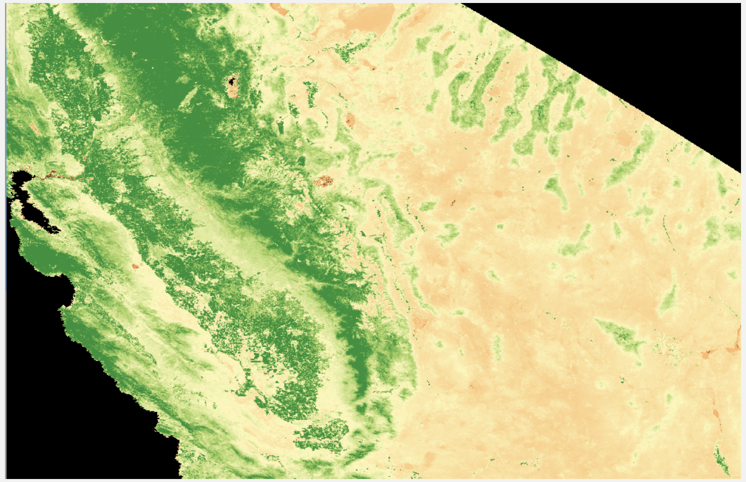
NDVI Anomalies in the southwestern United States. Image Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio.

NDVI Anomalies: Calculation Example



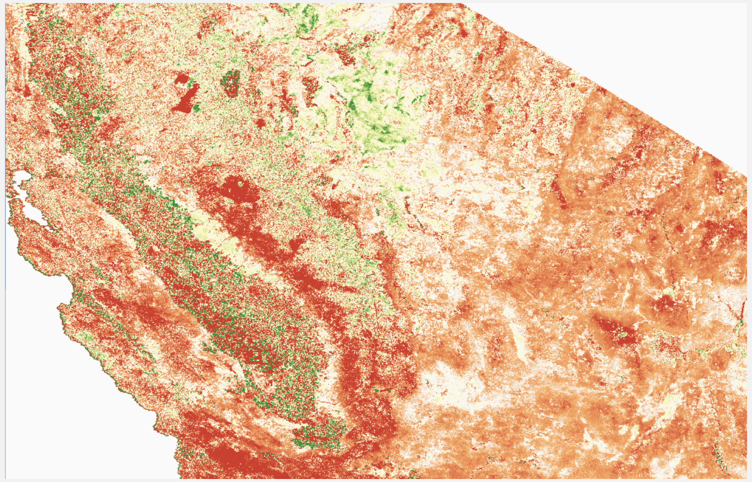
<u>Long-Term Average</u>

Calculate average July NDVI for 2001-2010



<u>NDVI for Month of Interest</u>

Obtain July 2015 NDVI



<u>Calculate Anomalies</u>

Subtract average monthly NDVI (2001-2010) from July 2015 NDVI

NDVI Anomaly Example: California Drought

- Image shows the NDVI anomalies from January 17 to February 1, 2014, against average conditions over the same period from the past decade
- Notice the below-average vegetation along most of the Central Valley farmland
- Vegetation in the Sierra Nevada is greener then usual, this is mainly because of a lack of snow, which is also bad news for California

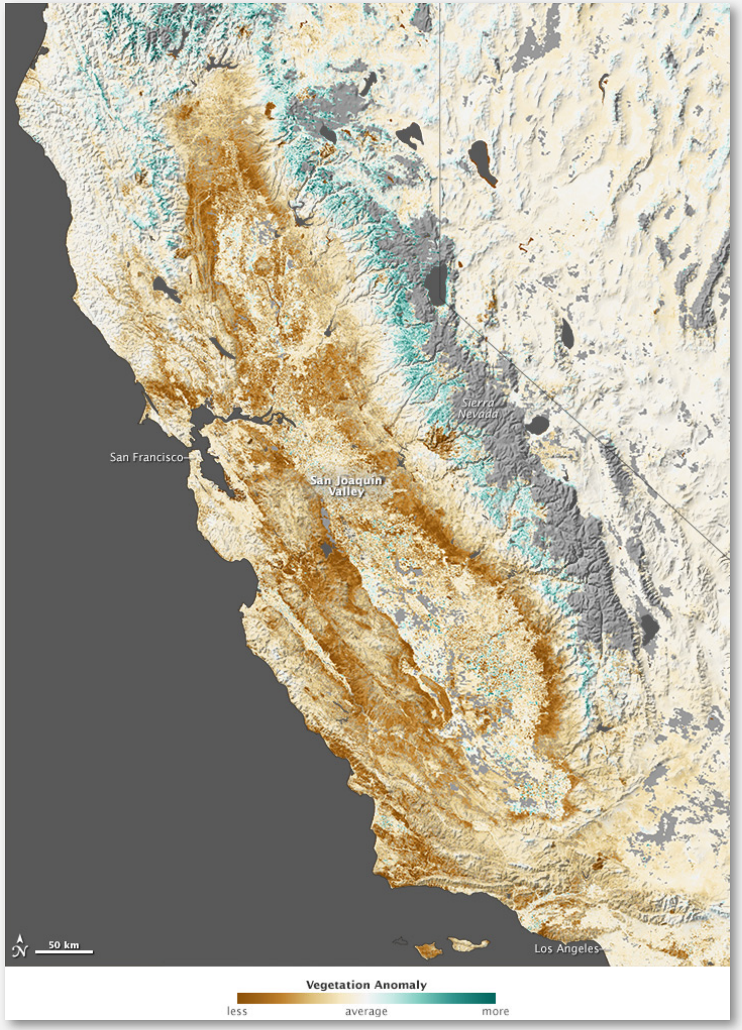
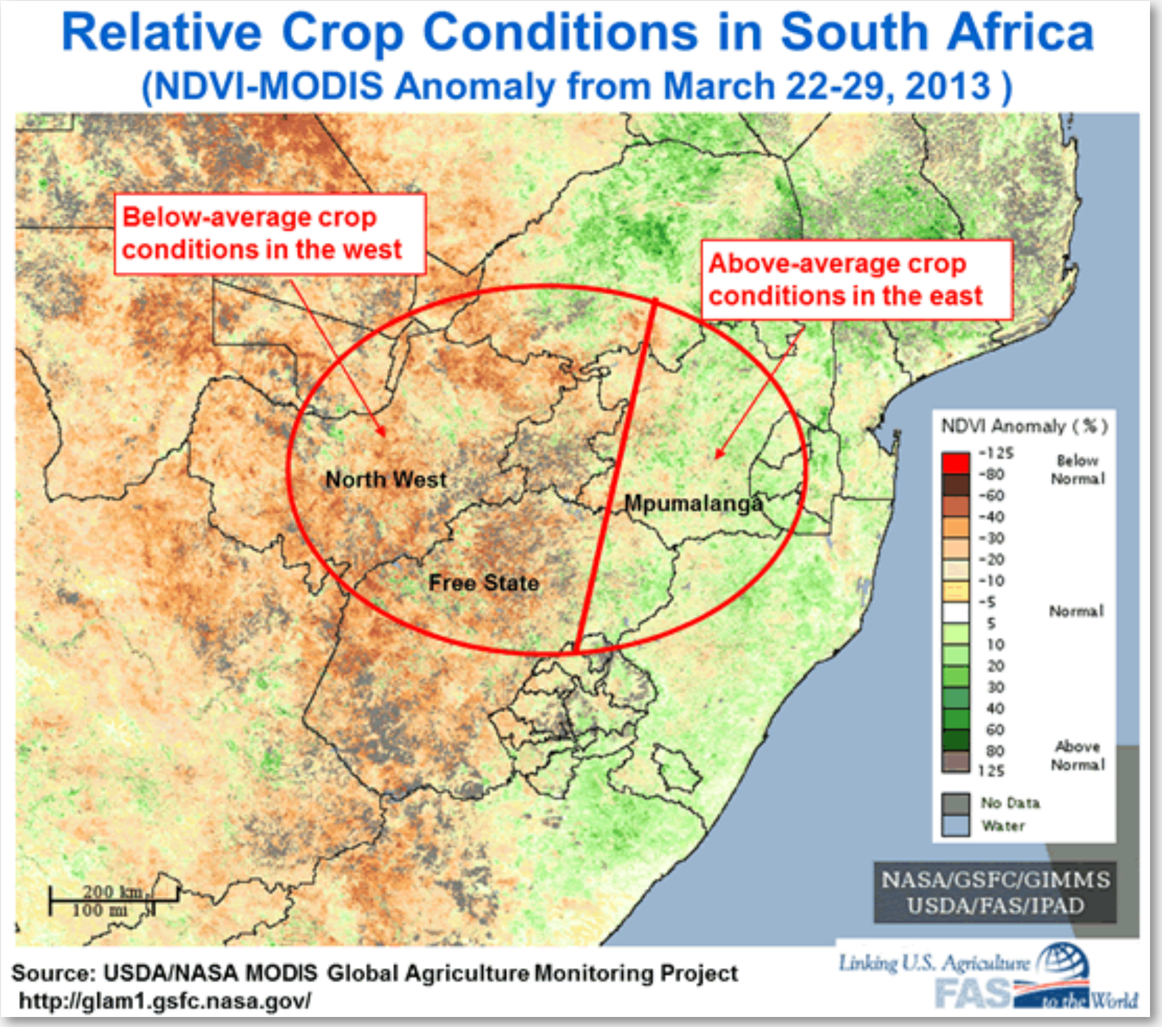


Image Credit: NASA Earth Observatory

NDVI Anomaly Example: South Africa

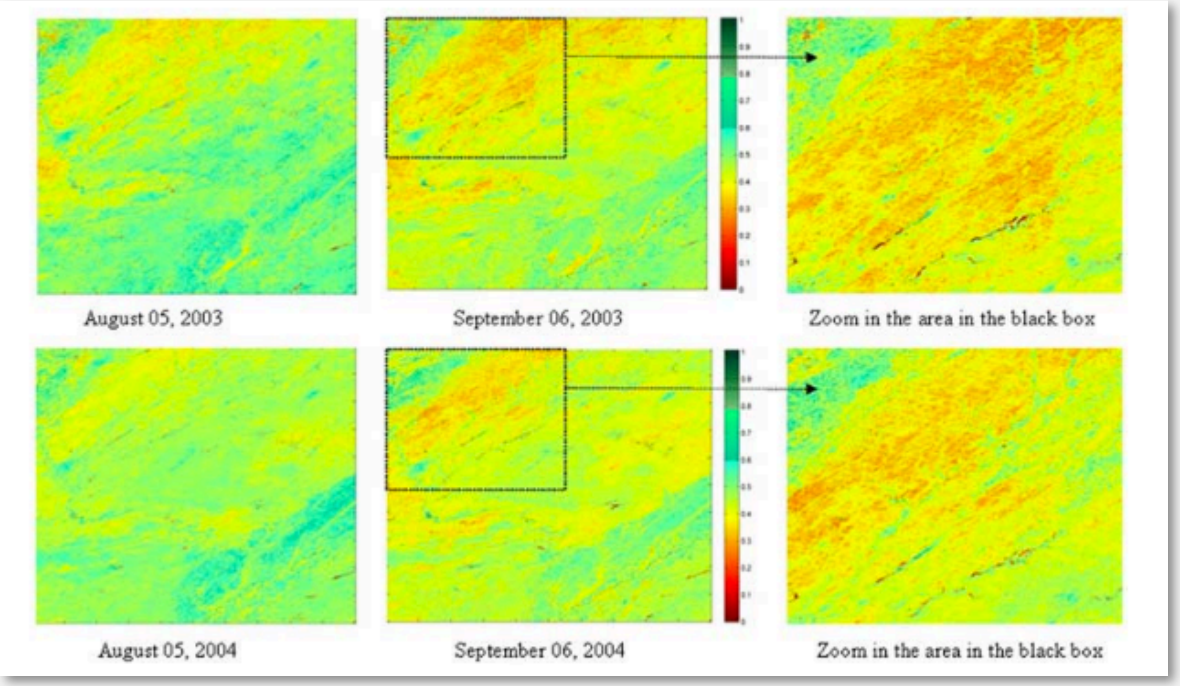
- South Africa's crop conditions at the end of March are summarized in the NDVI-MODIS anomaly
- Indicates below-average crop conditions in both the northwest and western Free State provinces and above-average crop conditions in Mpumalanga province



Normalized Difference Moisture Index (NDMI)

- Measure of vegetation moisture
- Frequently used in drought monitoring
  - detects more subtle changes in vegetation moisture
- Used in wildfire hazard potential

$$NDMI = \frac{(NIR - SWIR)}{NIR + SWIR}$$

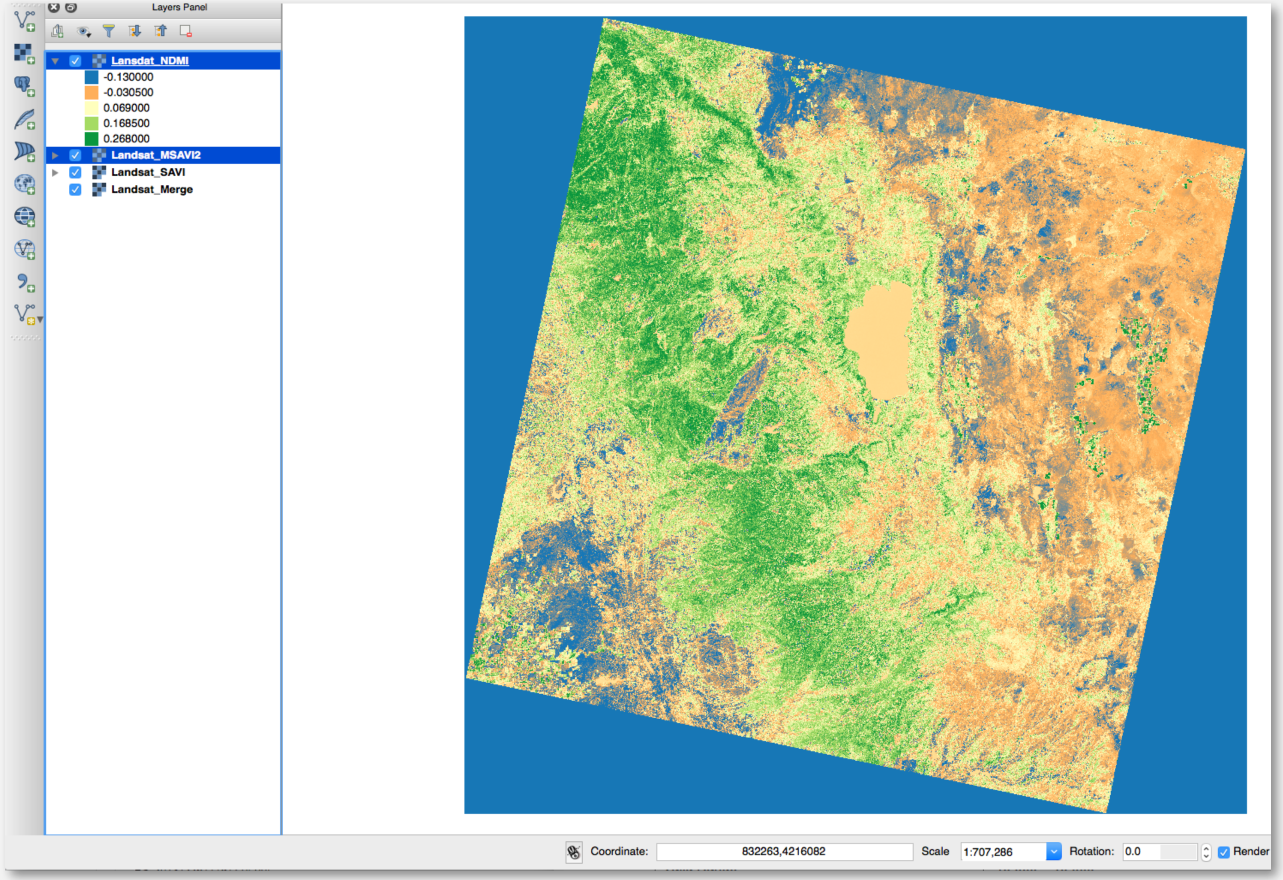


Example of NDMI. Image Credit: Wang and Qu, 2007

Normalized Difference Moisture Index (NDMI)

- Remember: Landsat Bands
  - Landsat 4-7
    - NIR = Band 4
    - SWIR = Band 5
  - Landsat 8
    - NIR = Band 5
    - SWIR = Band 6

$$NDMI = \frac{(NIR - SWIR)}{NIR + SWIR}$$



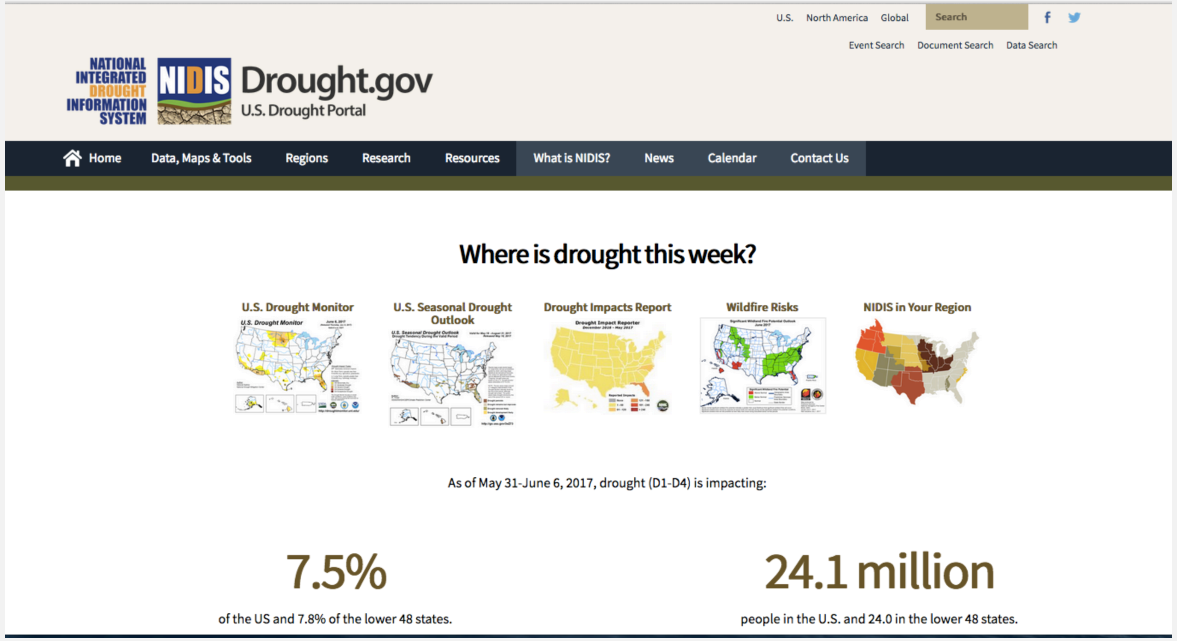
Example of NDMI using the California Landsat scene from week 2 exercise

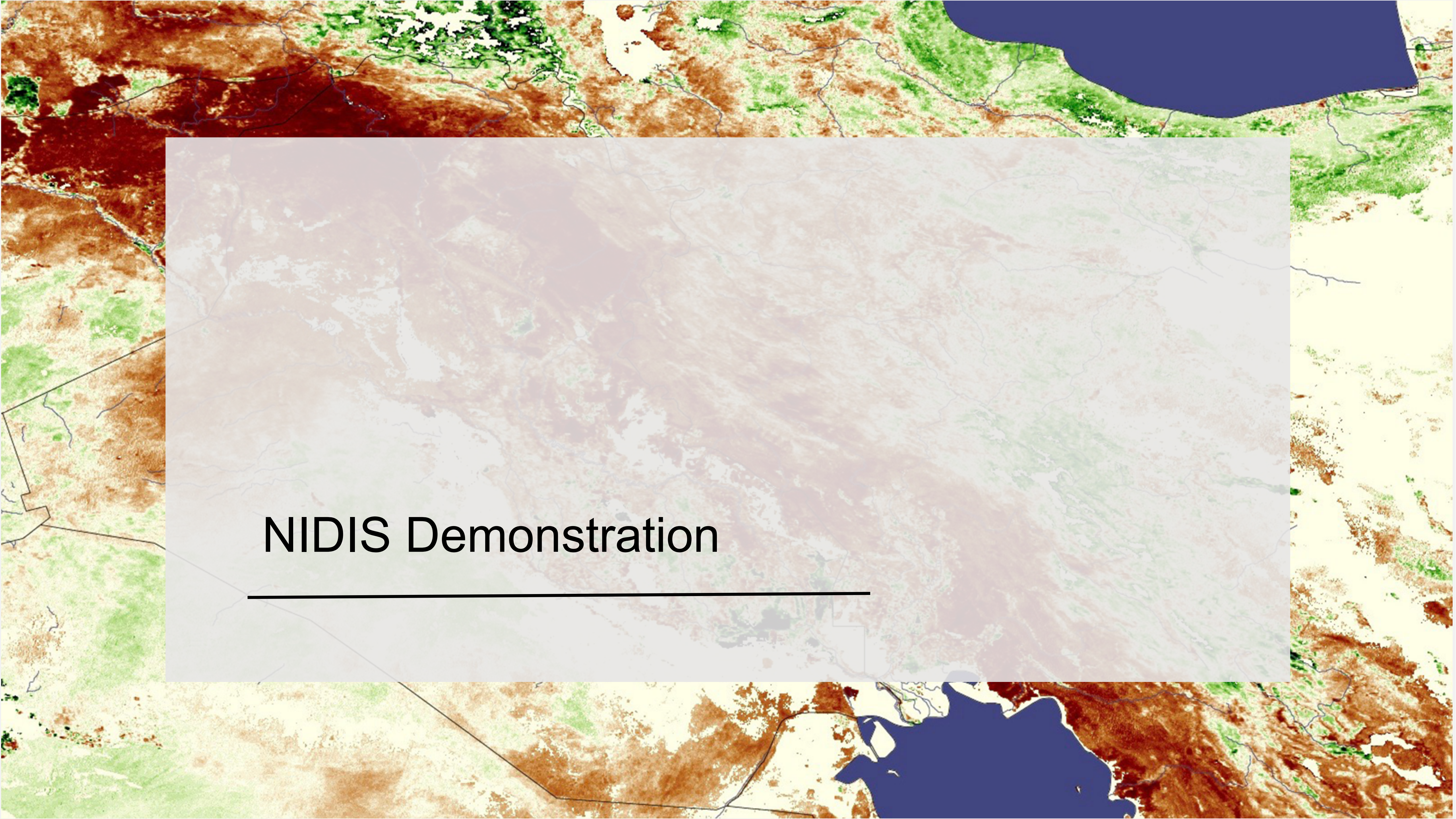
Introduction and Demonstration of Web-Based Drought Monitoring Tools

National Integrated Drought Information System (NIDIS)

http://www.drought.gov/drought/

- U.S. and global drought monitoring
- Provides
  - Surface-based precipitation, temperature, SPI, and PDSI
  - Satellite-based vegetation health index
- Interactive maps available





NIDIS Demonstration

U.S. Drought Monitor

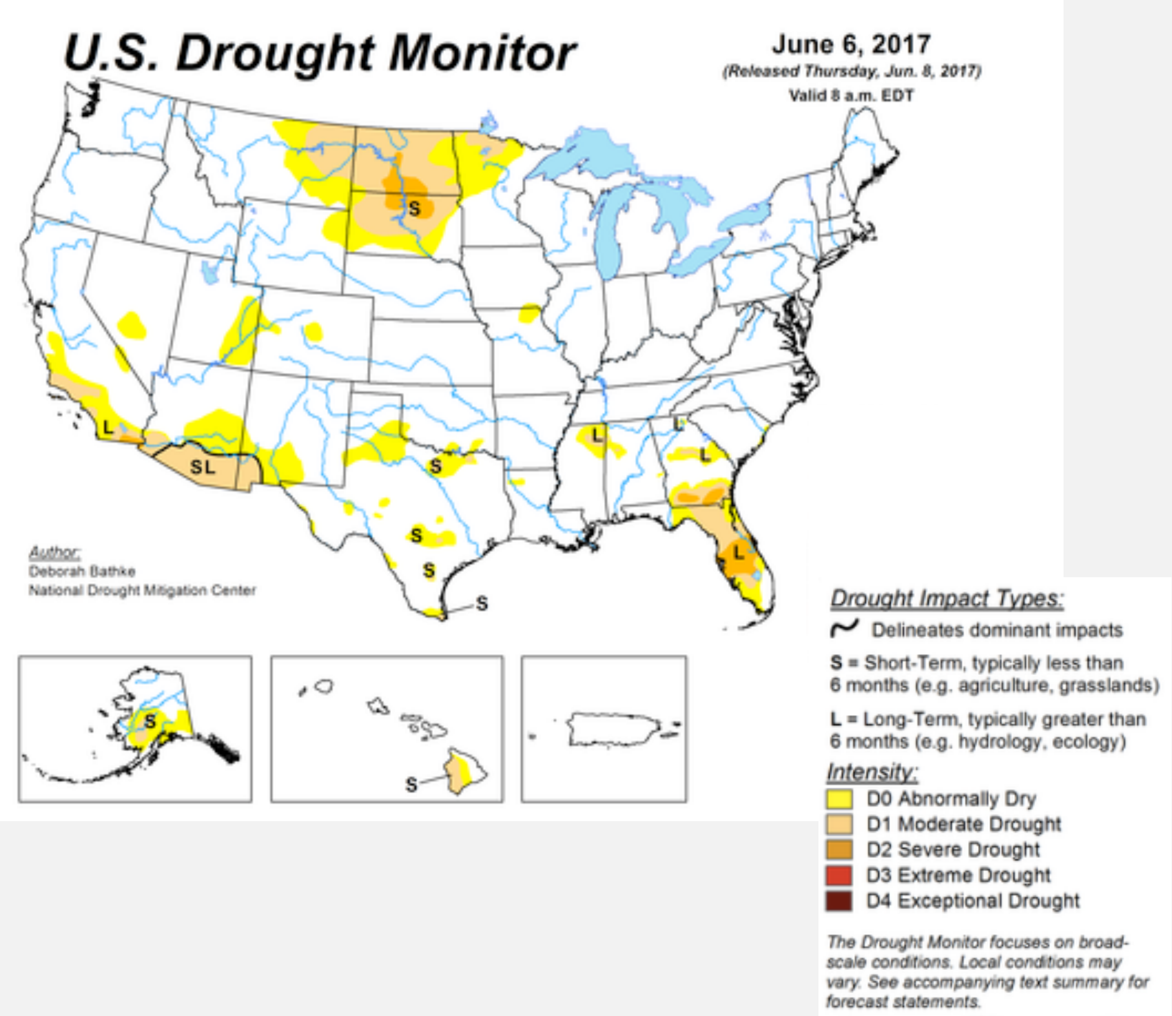
http://www.drought.gov/drought/

The weekly drought map shows drought severity, and impact types (Short, Long)

Drought Severity Classification

Category	Description	Possible Impacts	Ranges: Palmer Drought Severity Index (PDSI)	Ranges: CPC Soil Moisture Model (Percentiles)	Ranges: USGS Weekly Streamflow (Percentiles)	Ranges: Standardized Precipitation Index (SPI)	Ranges: Objective Drought Indicator Blends (Percentiles)
D0	Abnormally Dry	Going into drought: ▪ short-term dryness slowing planting, growth of crops or pastures Coming out of drought: ▪ some lingering water deficits ▪ pastures or crops not fully recovered	-1.0 to -1.9	21 to 30	21 to 30	-0.5 to -0.7	21 to 30
D1	Moderate Drought	▪ Some damage to crops, pastures ▪ Streams, reservoirs, or wells low, some water shortages developing or imminent ▪ Voluntary water-use restrictions requested	-2.0 to -2.9	11 to 20	11 to 20	-0.8 to -1.2	11 to 20
D2	Severe Drought	▪ Crop or pasture losses likely ▪ Water shortages common ▪ Water restrictions imposed	-3.0 to -3.9	6 to 10	6 to 10	-1.3 to -1.5	6 to 10
D3	Extreme Drought	▪ Major crop/pasture losses ▪ Widespread water shortages or restrictions	-4.0 to -4.9	3 to 5	3 to 5	-1.6 to -1.9	3 to 5
D4	Exceptional Drought	▪ Exceptional and widespread crop/pasture losses ▪ Shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0 to 2	0 to 2	-2.0 or less	0 to 2

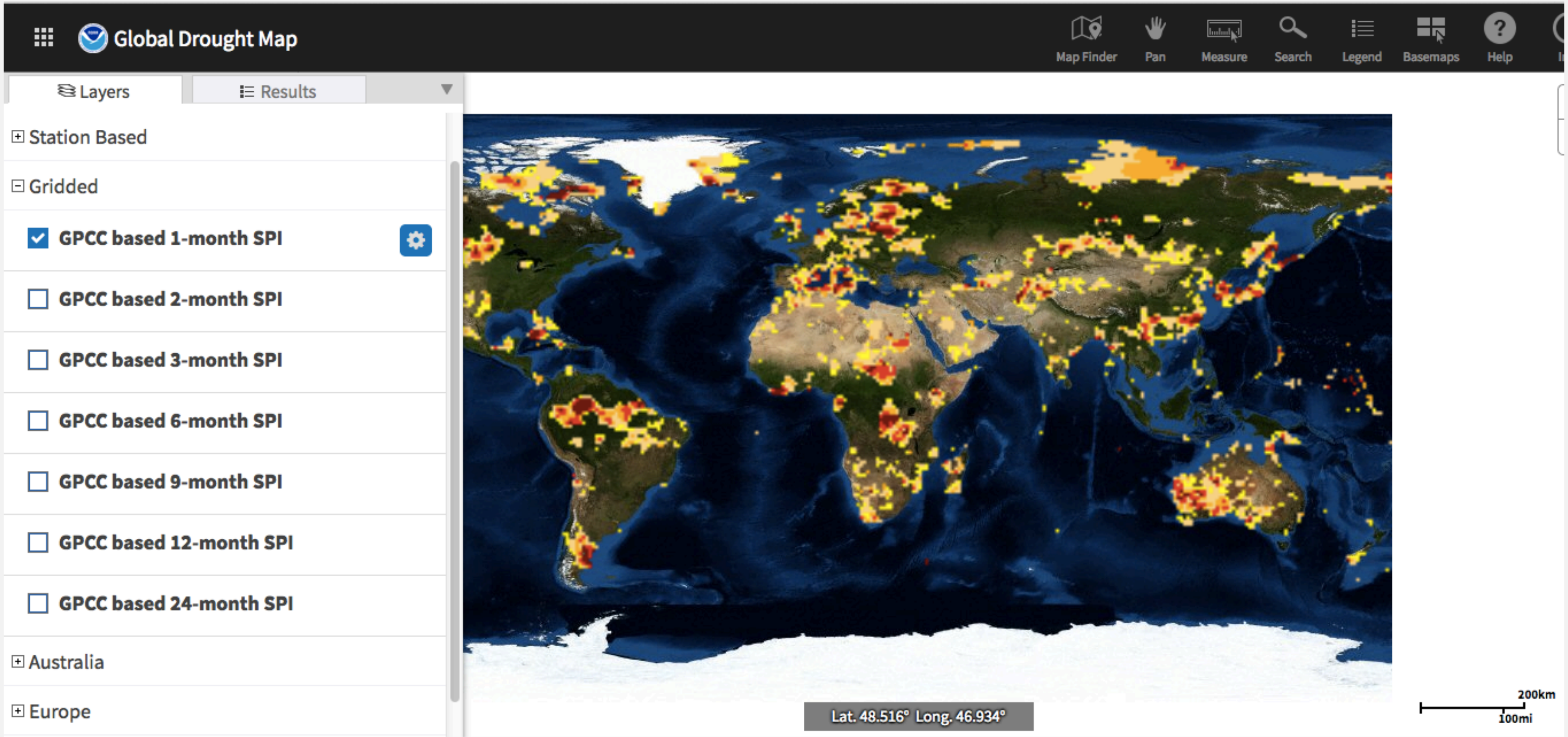
Short-term drought indicator blends focus on 1-3 month precipitation. Long-term blends focus on 6-60 months. Additional indices used, mainly during the growing season, include the USDA/NASS Topsoil Moisture, Keetch-Byram Drought Index (KBDI), and NOAA/NESDIS satellite Vegetation Health Indices. Indices used primarily during the snow season and in the West include snow water content, river basin precipitation, and the Surface Water Supply Index (SWSI). Other indicators include groundwater levels, reservoir storage, and pasture/range conditions.



Credit: http://droughtmonitor.unl.edu/AboutUs/ClassificationScheme.aspx

Global Drought Monitor

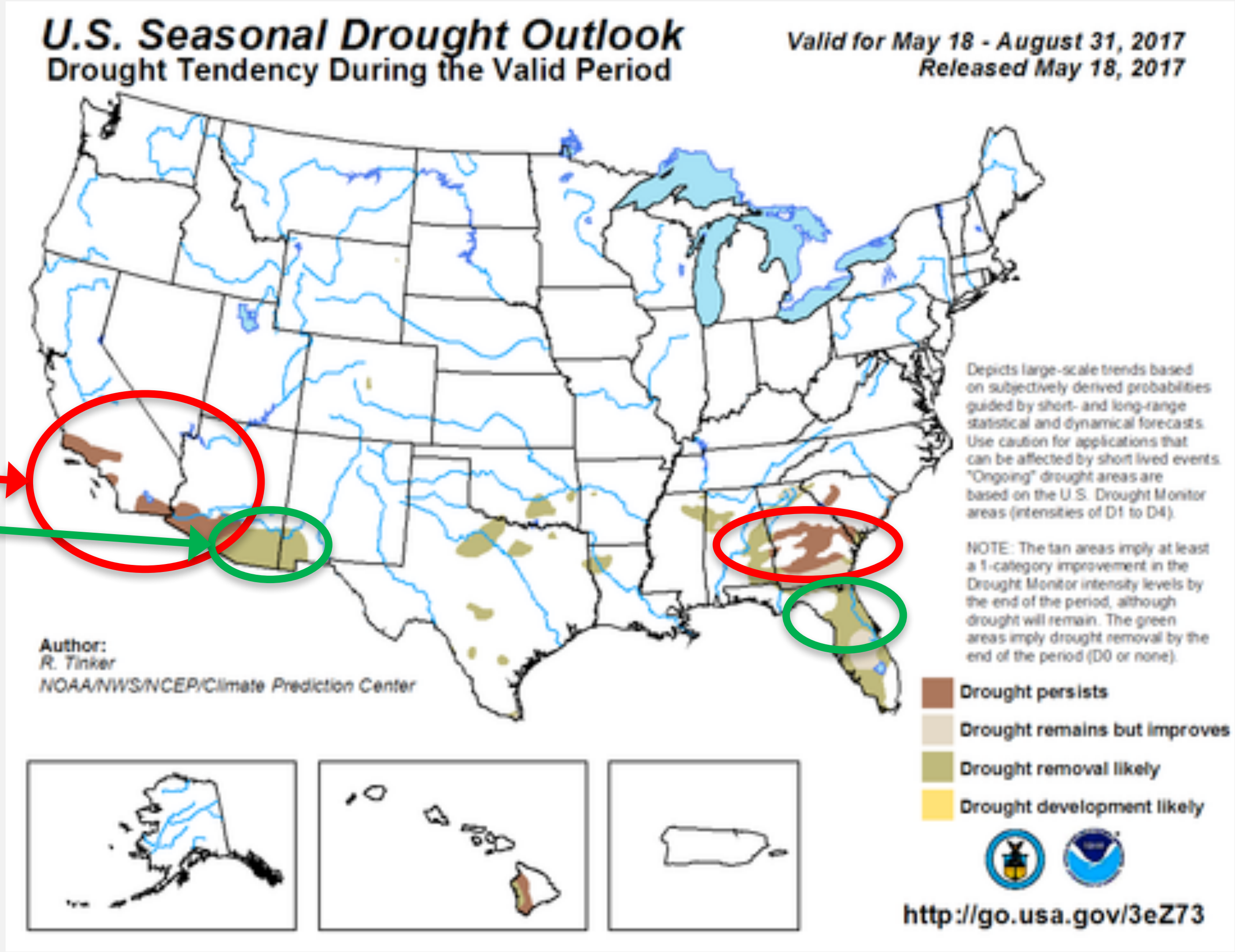
http://gis.ncdc.noaa.gov/maps/ncei/drought/global/



U.S. Seasonal Drought Outlook

http://www.drought.gov/drought/

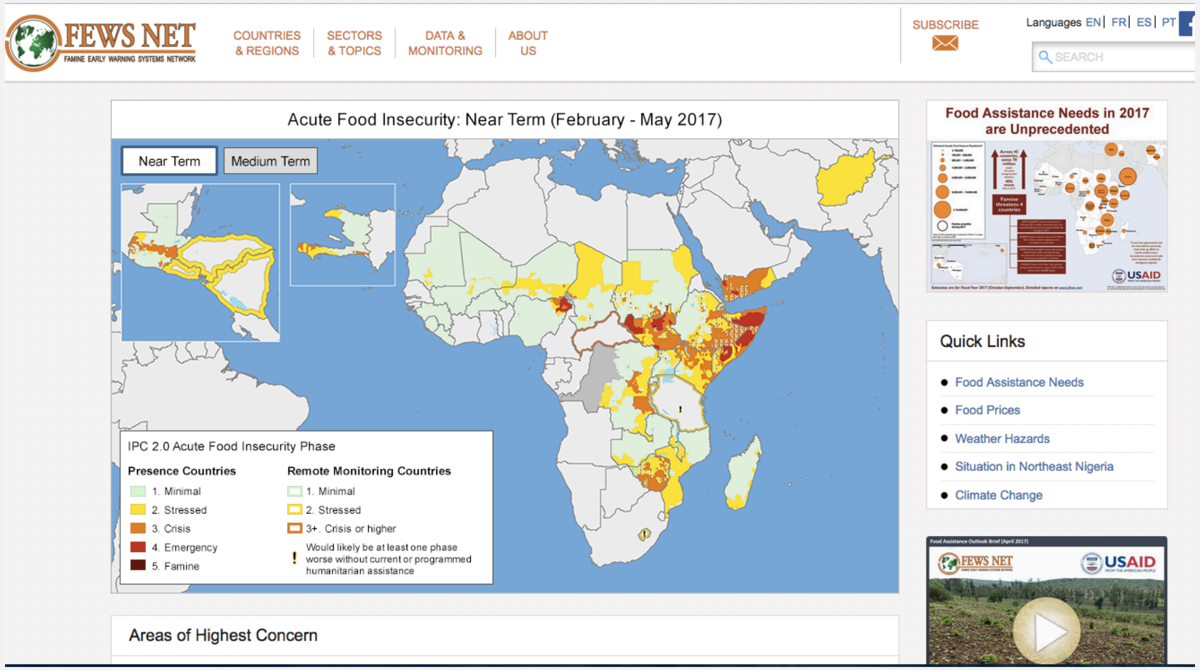
June to September 2017 outlook based on NOAA Climate Prediction Center, with persistent droughts and likely drought recovery in certain areas



Famine Early Warning System Network (FEWS NET)

http://www.fews.net/

- Created by USAID in 1985
- A joint project among NASA, NOAA, USDA, and USGS
- Uses MODIS NDVI and TRMM in preparing rainfall climatology
- Provides evidence-based famine analysis to help government decision-makers and relief agencies plan for and respond to humanitarian crises

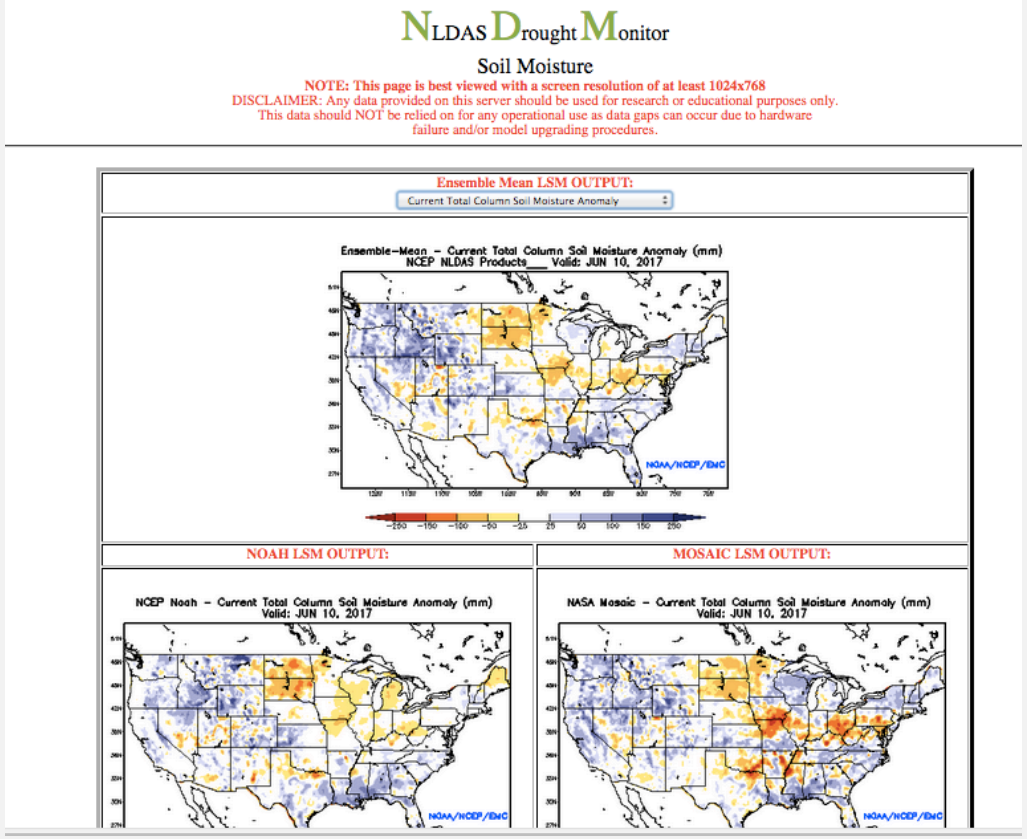


FEWS NET Demonstration

North American Land Data Assimilation Drought Monitor

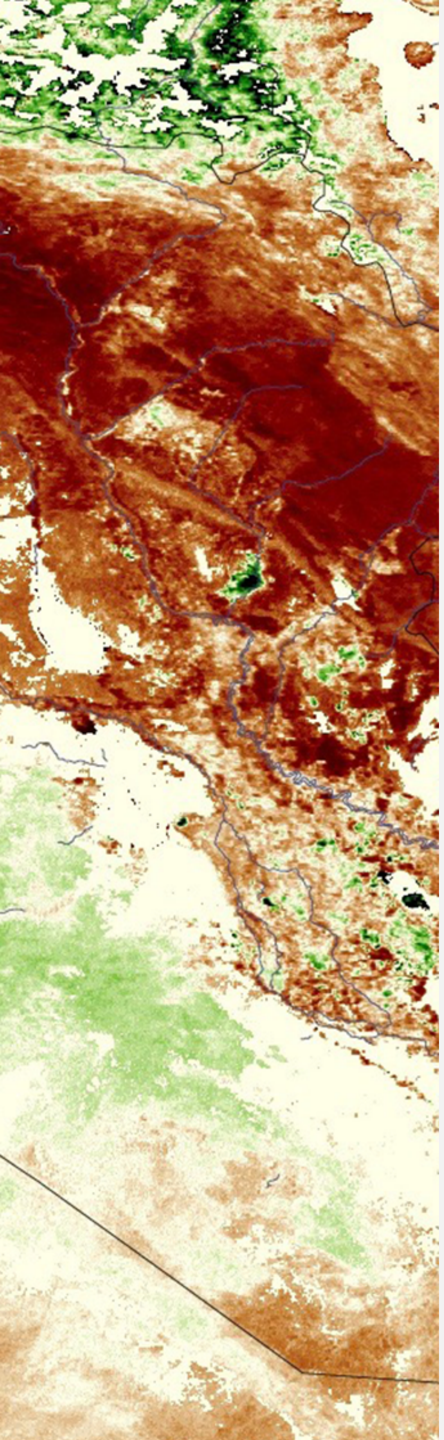
http://www.emc.ncep.noaa.gov/mmb/nldas/drought/

- Experimental drought monitor based on a land surface model that assimilates remote sensing observations
- North American Land Data Assimilation (NLDAS) model has four versions, including NASA MOSAIC, and Princeton University Visible Infiltration Capacity (VIC)
- For detailed information on NLDAS see Fundamentals of Remote Sensing: Session 2B
  – http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing



NLDAS Drought Monitor Demonstration

Exercise: Download Precipitation, NDVI, and Soil Moisture Data



National Aeronautics and
Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

Thank You

Next Week: Drought Monitoring Analysis and Application