National Aeronautics and Space Administration

Satellite Remote Sensing for Agricultural Applications

Sean McCartney, Amita Mehta, and Erika Podest

April 14, 2020

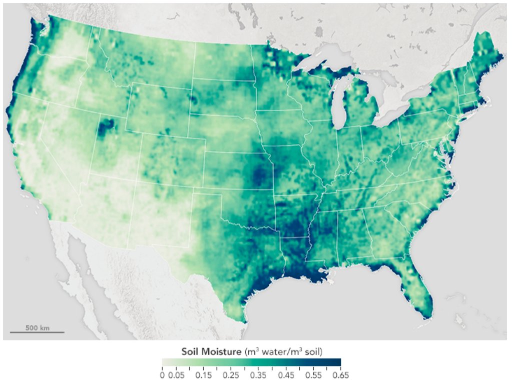
Training Outline

April 14, 2020

Overview of Agricultural Remote Sensing

https://eospso.nasa.gov/content/nasas-earth-observing-system-project-science-office

April 21, 2020



Soil Moisture for Agricultural Applications

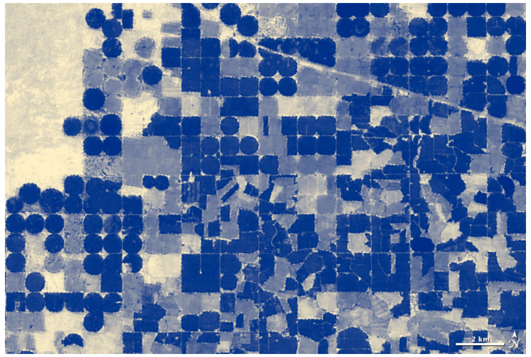
https://earthobservatory.nasa.gov/images/87036/soil-moisture-in-the-united-states

April 28, 2020

Earth Observations for Agricultural Monitoring

https://earthobservatory.nasa.gov/images/90095/satellites-eye-winter-cover-crops

May 5, 2020



Evapotranspiration & Evaporative Stress Index for Agricultural Applications

https://earthobservatory.nasa.gov/images/42428/water-use-on-idahos-snake-river-plain

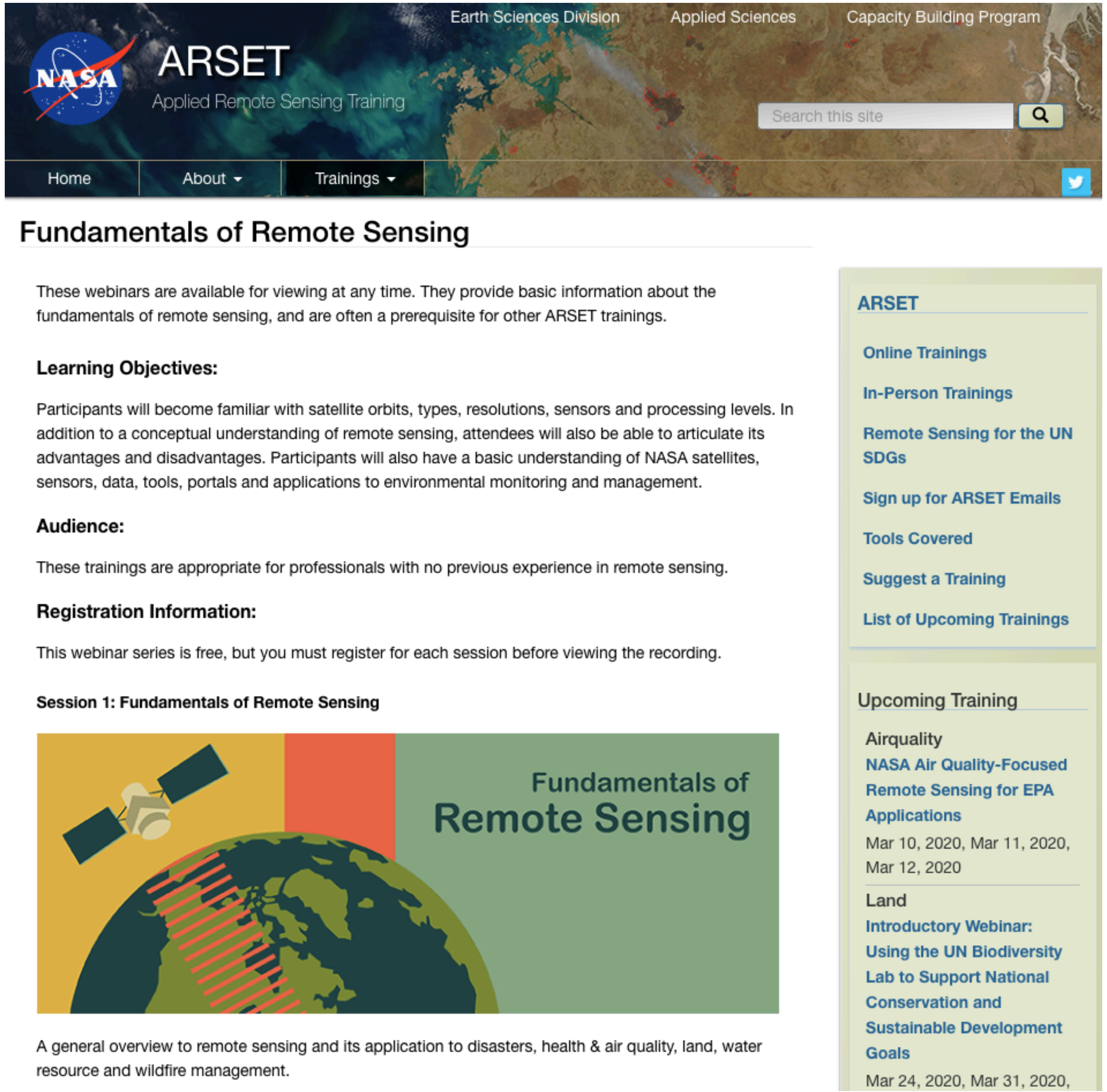
Training Format, Homework, and Certificate

- Four, 1.5-hour sessions with Q&A
- Homework Assignments will be available after parts 1 & 3 from: https://arset.gsfc.nasa.gov/water/webinars/remote-sensing-for-agriculture-20
  – Answers must be submitted via Google Form
  – Due dates: **April 28** & **May 12**
- A Certificate of Completion will be awarded to those who:
  – Attend all webinars
  – Complete all homework assignments
- You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Prerequisite

Fundamentals of Remote Sensing

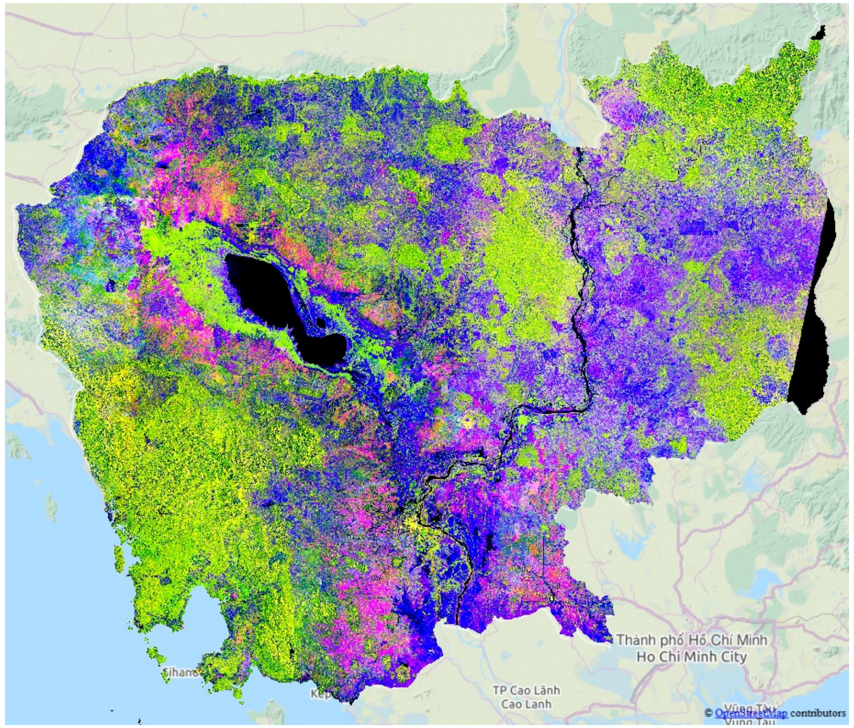
https://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing



Objectives

By the end of this presentation, you will identify:

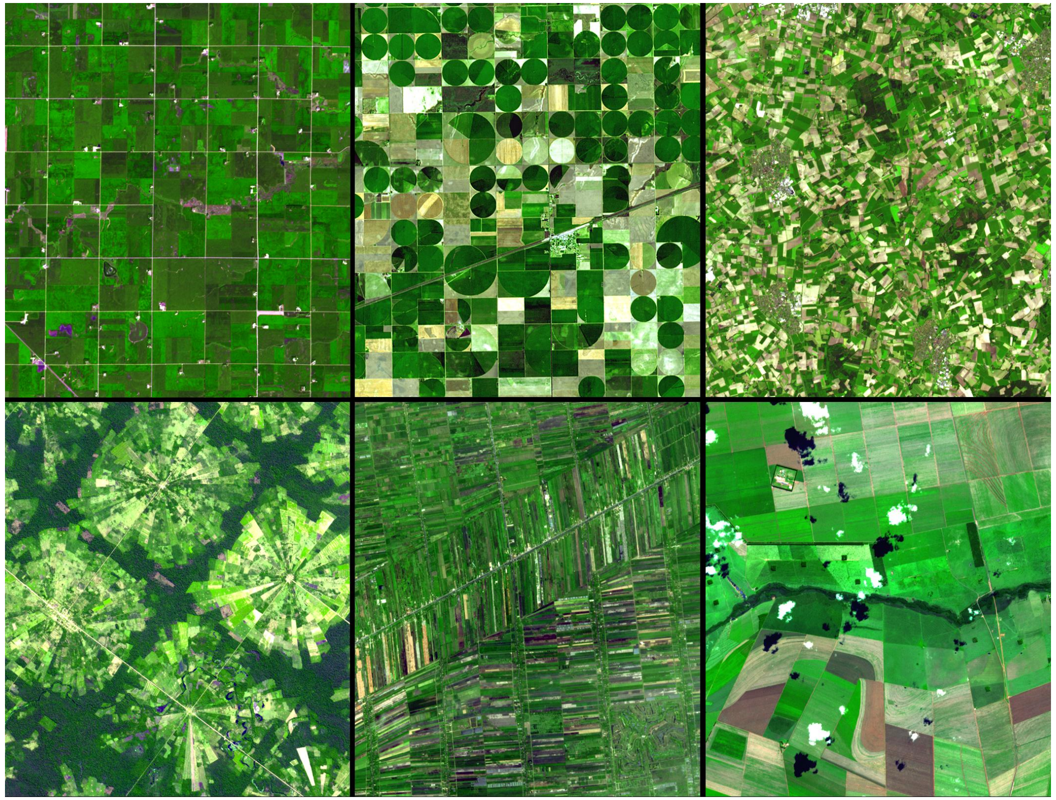
- Which satellites and sensors can be used for agricultural applications
- The specific scientific data products that are appropriate for agricultural applications
- The limitations of remote sensing and modeled data for agriculture and food security



Rice Extent in Cambodia
Image Credit: ESA

Part-1 Outline

- About ARSET
- History of Earth observations for agriculture
- Satellites & sensors for agricultural applications
- Caveats & limitations of remote sensing
- Introduction to NASA HARVEST
- Applications for agriculture and food security



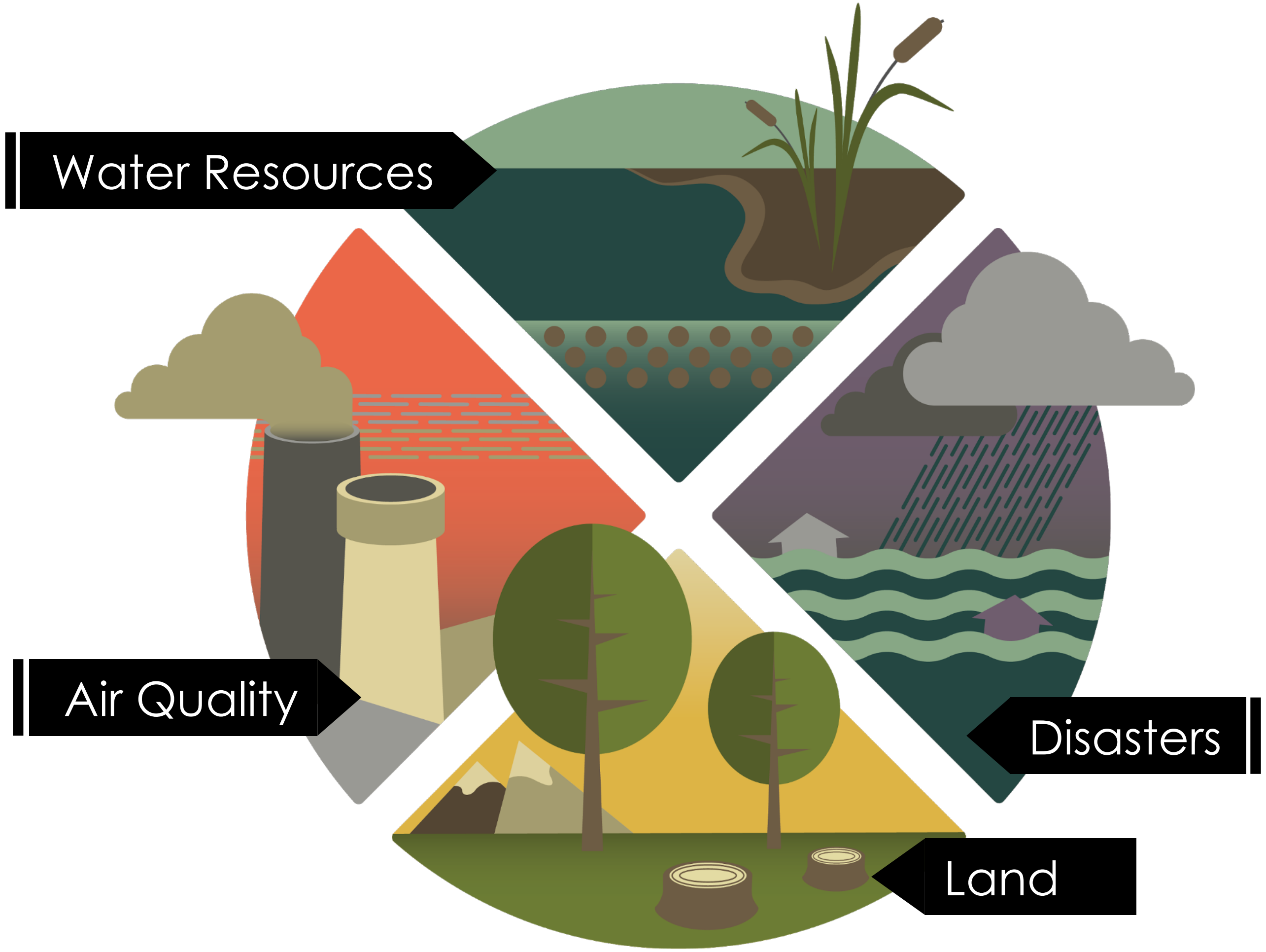
Agricultural Patterns
Image Credit: NASA

About ARSET

NASA’s Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov/

- Part of NASA’s Applied Sciences Capacity Building Program
- Empowering the global community through online and in-person remote sensing training
- Topics for trainings include:
  – Air Quality
  – Disasters
  – Land
  – Water Resources

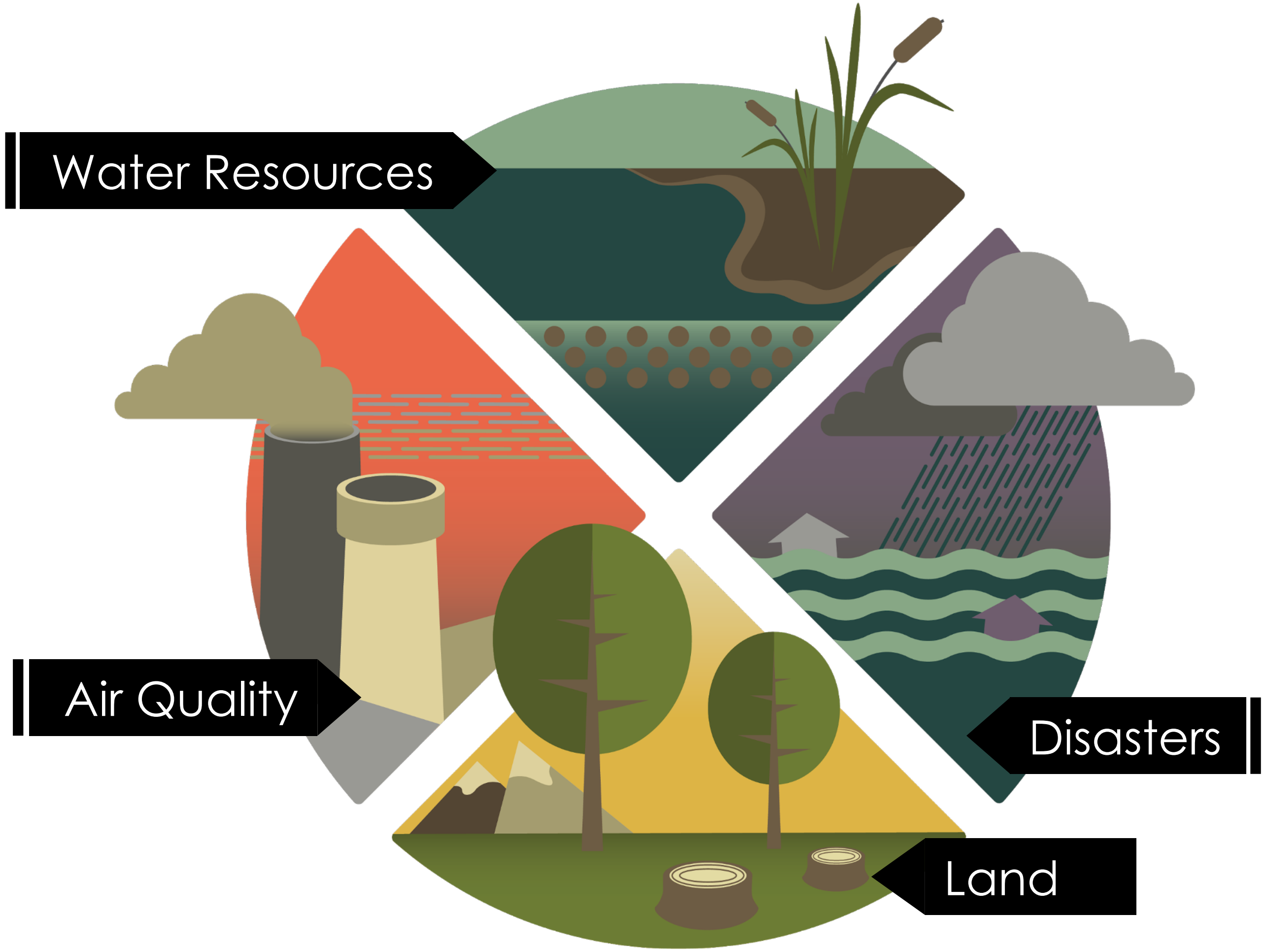


NASA's Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov/

- ARSET's goal is to increase the use of Earth science in decision-making through training for:
  - Policy makers
  - Environmental managers
  - Other professionals in the public and private sector

- **All ARSET materials are free and available for you to use and adapt. If you use the methods and data presented in ARSET trainings, please acknowledge the NASA Applied Remote Sensing Training (ARSET) program**



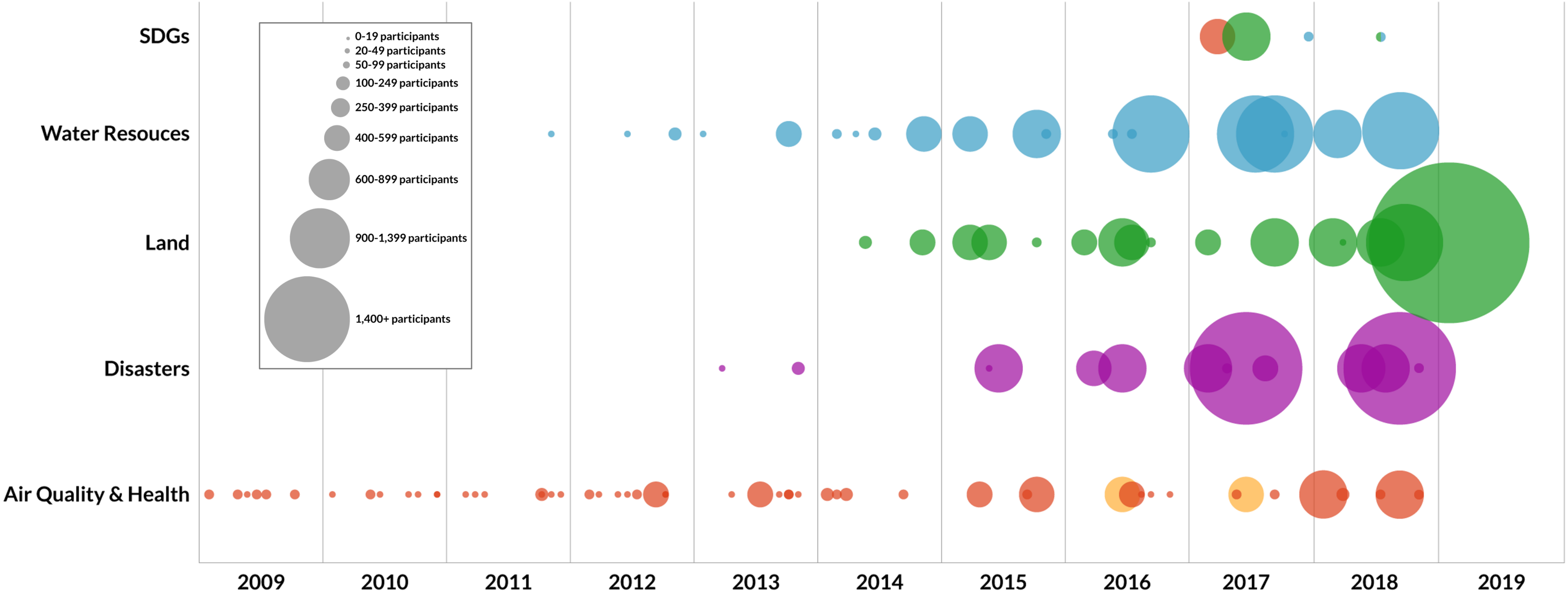
ARSET Trainings

130+ trainings

30,000+ participants

165+ countries

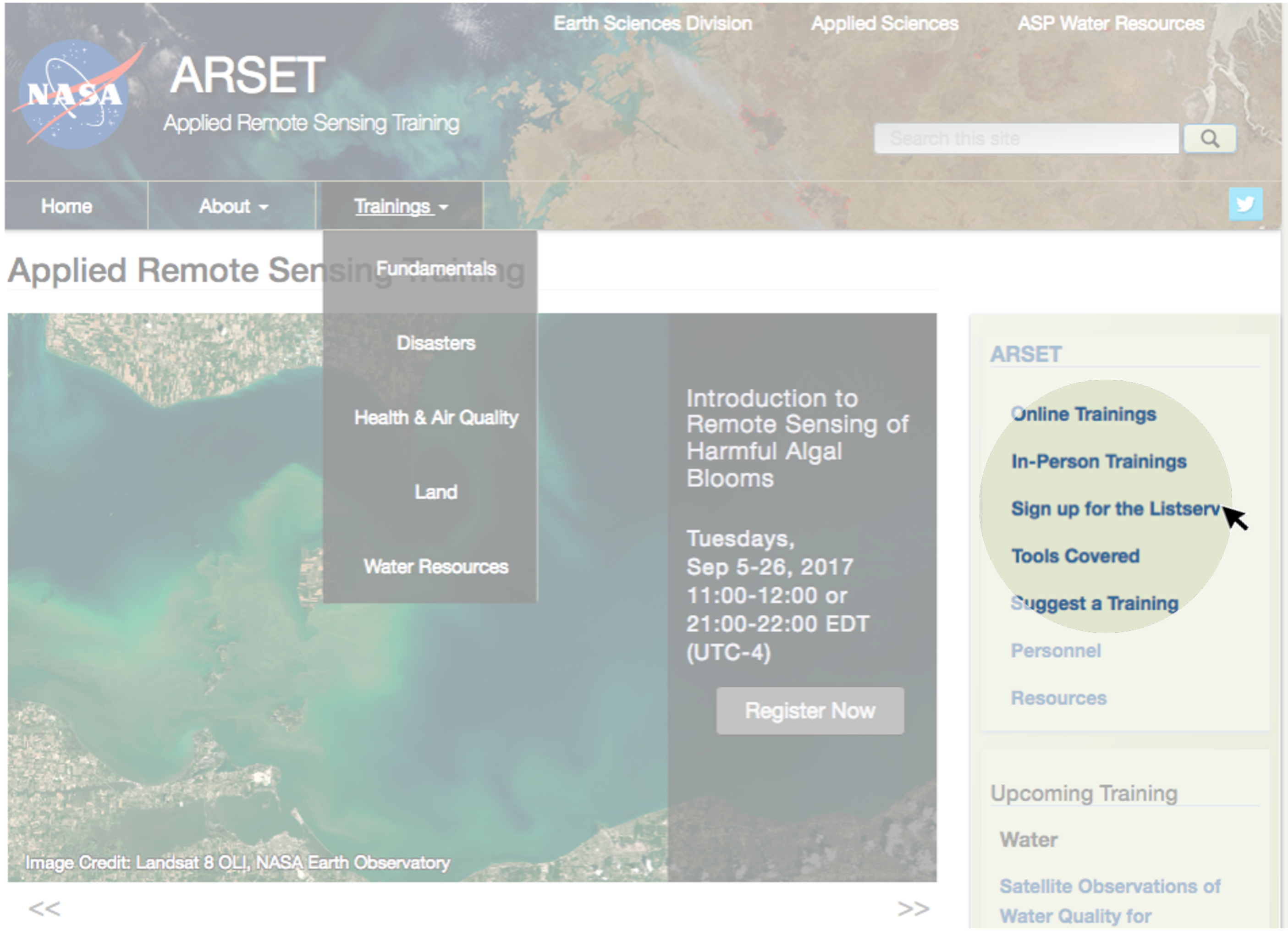
8,200+ organizations



* Bubble size corresponds to number of attendees

Learn More About ARSET

http://arset.gsfc.nasa.gov/



History of Remote Sensing for Agriculture

Background

- Statement of Agreement between the U.S. Department of Agriculture (USDA)-Agricultural Research Service (ARS) and NASA (1965)
  - Formally began ARS's remote sensing research
  - Objectives were to characterize the reflectance and emission signatures of different land covers (crops and range) that would permit their identification using sensors on aircraft and satellite platforms
  - Led to the design of the first sensors carried on Landsat 1 (originally named Earth Resources Satellite-1)
  - https://naldc.nal.usda.gov/download/54865/PDF

Background

- Great Grain Robbery (1972)
  - Crop shortfalls in the Soviet Union in 1971 & 1972 led the government to global markets to meet domestic demand
  - U.S. subsidized grain sales to Soviet negotiators at below market prices due to a lack of spatially explicit information on the scale of crop failure
  - Markets adjusted to worldwide grain shortfalls and increased demand
  - Considerable disruption in the U.S. and global grain markets
  - https://earthzine.org/the-great-grain-robbery-of-1972/

Image Credit: WW2 Cartoons

Background

- Landsat 1 (originally named "Earth Resources Satellite-1")
  - Launched on July 23, 1972
  - Sensor: Multispectral Scanner (MSS)
    - Spectral range: 0.5 – 1.1 µm (green, red, and two infrared bands)
  - First Earth observing satellite to be launched with the express intent to study and monitor the planet's landmasses
  - Development of crop production forecasts via satellite monitoring, beginning a global agricultural monitoring system that continues to this day
  - https://landsat.gsfc.nasa.gov/landsat-1/

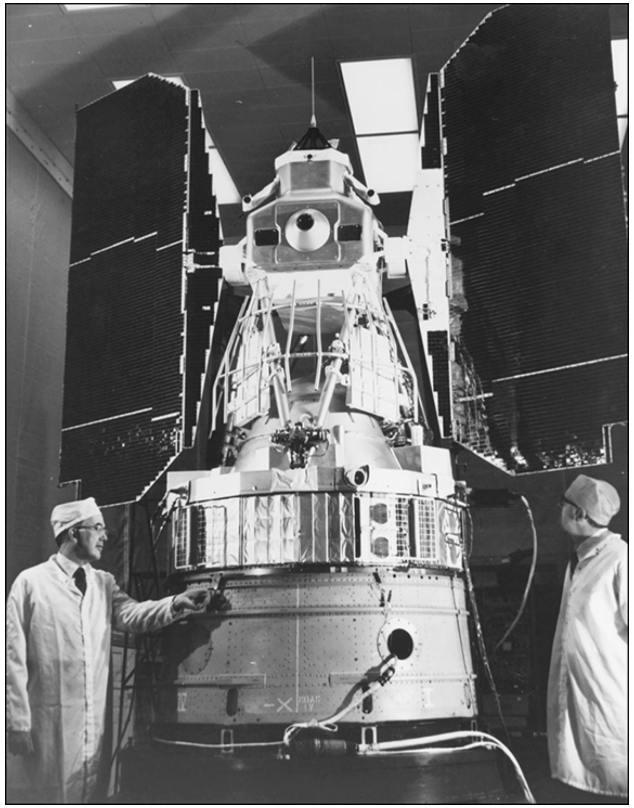


Image Credit: NASA

Background

- Large Area Crop Inventory Experiment (LACIE)
  - Joint undertaking by USDA, NASA, and NOAA over three global crop seasons (1974-1977)
  - Utilized the observational capabilities afforded by Landsat together with estimates of weather variables to estimate wheat production
  - Phase 1: Focus on determining wheat area and yield in the U.S. Great Plains
  - Phase 2: Focus on wheat area and yield in major grain-producing countries
  - Proved an economically important application of multispectral remote sensing from space

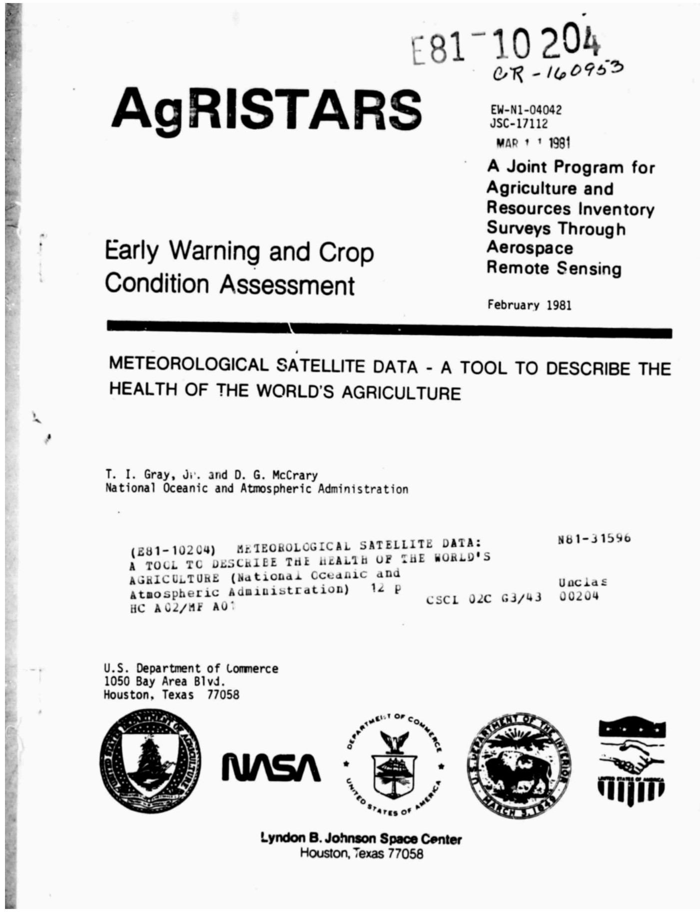
Background

- ARS Wheat Yield Project (1976)
  - Conducted across the U.S. in regions where wheat was the predominant crop
  - Helped design of wideband radiometers and infrared radiation thermometers for in situ observations
  - Made in situ observations and began to develop remote sensing methods for assessing normal plant condition and providing early warning of plant stress
  - Collective research made linkage among remotely sensed crop parameters, development and yield models, and observations from satellites being used to estimate global wheat crop yields

Wheat field
Image Credit: Suzy Dubot

Background

- Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS)
  - Program initiated in 1980
  - Aimed toward developing a better understanding of how electromagnetic radiation interacts with agricultural targets
  - Goal was to expand upon LACIE and include monitoring of other commodity crops such as soybeans, maize, rice, cotton, and barley
  - Combination of spectral, environmental, agronomic, and in situ data to improve the predictive utility of yield forecasting



E81-10204
CR-160953

AgRISTARS

EW-N1-04042
JSC-17112

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

February 1981

Early Warning and Crop Condition Assessment

METEOROLOGICAL SATELLITE DATA - A TOOL TO DESCRIBE THE HEALTH OF THE WORLD'S AGRICULTURE

T. I. Gray, Jr. and D. G. McCrary
National Oceanic and Atmospheric Administration

(E81-10204) METEOROLOGICAL SATELLITE DATA: A TOOL TO DESCRIBE THE HEALTH OF THE WORLD'S AGRICULTURE (National Oceanic and Atmospheric Administration) 12 p HC A02/MF A01 CSCL 02C G3/43 N81-31596 Unclas 00204

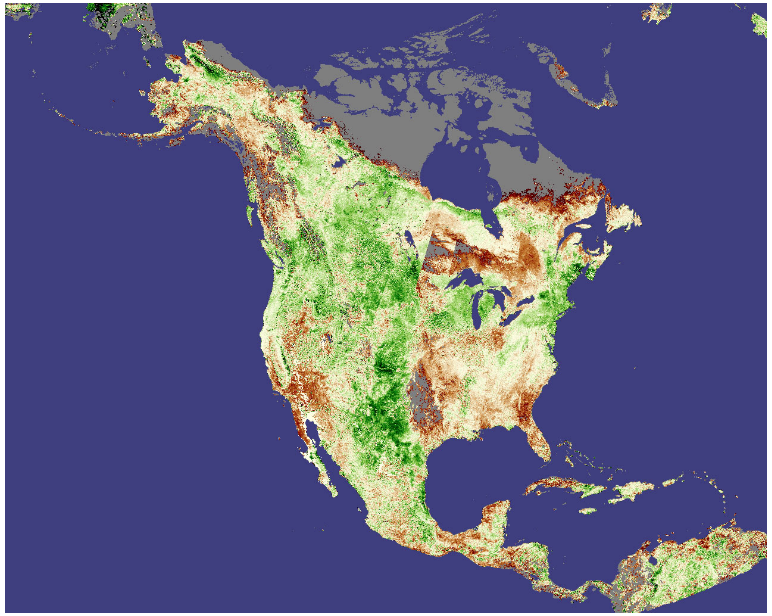
U.S. Department of Commerce
1050 Bay Area Blvd.
Houston, Texas 77058

NASA

Lyndon B. Johnson Space Center
Houston, Texas 77058

Background

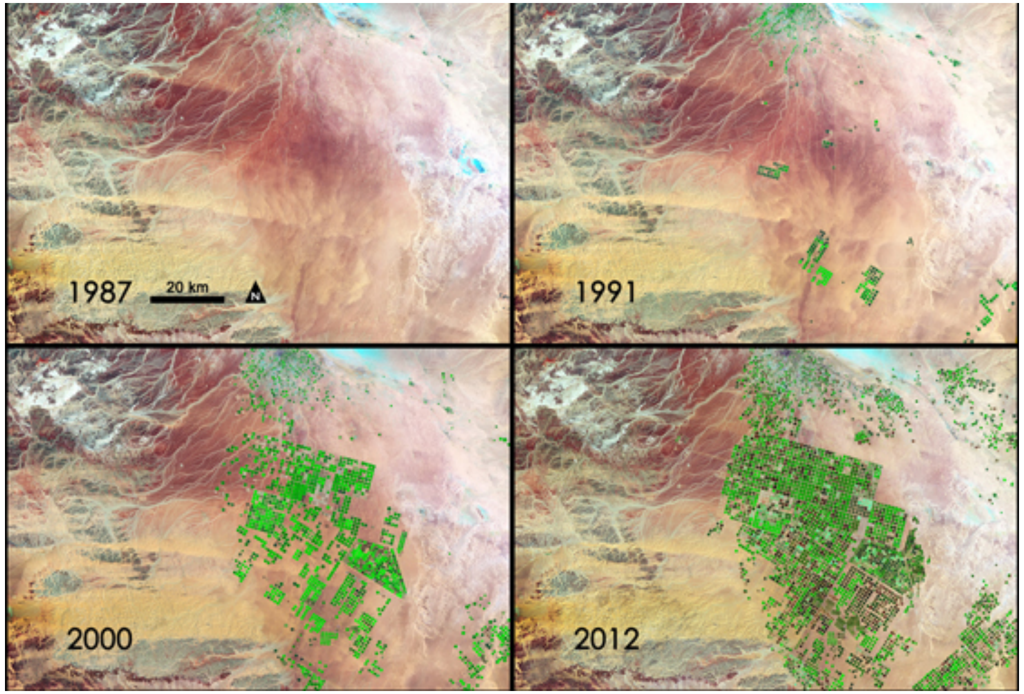
- Advanced Very High-Resolution Radiometer (AVHRR)
  - Originally designed for meteorological applications
  - From NOAA-6 (1979) and subsequent Polar-orbiting Operational Environmental Satellites (POES), changes were made to narrow the spectral channels allowing for vegetation monitoring and calculation of Normalized Difference Vegetation Index (NDVI)
  - For the first time, vegetation could be monitored at a global scale from a satellite platform with a high temporal frequency of repeat observations
  - 40-year history of daily, global NDVI measurements



NDVI anomaly in May 2007 derived from AVHRR data
Image Credit: NASA

Why use satellites for agriculture applications?

- Timely, objective, local to global coverage
- Useful for observing areas that are inaccessible
- Monitor plant growth and estimate crop productivity
- Assess soil moisture and irrigation requirements
- Identify soil and crop characteristics and conditions
- Better forecast precipitation and crop disease
- Maximize crop yields while reducing energy consumption
- Avoid waste of farm inputs (water, fertilizer, and pesticide)



Evolution of agricultural operations in the Wadi As-Sirhan Basin, Saudi Arabia. Captured by Landsat satellites 4, 5, and 7 in 1987, 1991, 2000, and 2012. Taken by Thematic Mapper and Enhanced Thematic Mapper Plus. Image Credit: NASA

Applications for Agriculture and Food Security

- Crop Monitoring
  – Phenology, crop area, crop type, crop condition, yield, irrigated landscape, flood, drought, frost, accurate and timely reporting of agricultural statistics
- Crop Forecasting
  – Accurate forecasting of yield or shortfalls in crop production and food supply per region and country
- Market Stability
  – Lowers uncertainty and increases the transparency of global food supply
  – Reduces price volatility by anticipating market trends with reduced uncertainty
- Humanitarian Aid
  – Monitor food security in high-risk regions worldwide
  – Early warning of famine, enabling the timely mobilization of an international response in food aid

Biophysical Characteristics Derived from Remote Sensing

- Derived biophysical characteristics of vegetation:
  - Chlorophyll Content
  - Above Ground Biomass
  - Leaf Area Index (LAI)
    - One-sided green leaf area per unit ground area in broadleaf canopies & half the total needle surface area per unit ground area in coniferous canopies
  - Photosynthetic Primary Production
    - Measure of how much CO_2 vegetation takes in during photosynthesis minus how much CO_2 the plants release during respiration
  - Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)
    - Represents the ratio of solar radiation that is absorbed by vegetation for photosynthesis (used for assessing the impacts of drought on vegetation)

Satellites & Sensors for Agricultural Applications

Satellites & Sensors for Agricultural Applications

		Scientific Products						
Satellite	**Sensor**	**Land Surface Reflectance**	**Evapotranspiration**	**Land Surface Temperature**	**Precipitation**	**Soil Moisture**	**Vegetation Greenness**	**Structure**
Terra	MODIS	X	X	X			X	
Aqua	MODIS	X	X	X			X	
Suomi-NPP	VIIRS	X		X			X	
NOAA-20	VIIRS	X		X			X	
Landsat 8	OLI	X					X	
Sentinel 2	MSI	X					X	
Landsat 8 & Sentinel 2	HLS	X					X	
International Space Station	ECOSTRESS		X					
Land Data Assimilation System	Modeled output		X			X		
Global Precipitation Measurement	GMI, DPR				X			
CHIRPS	Multiple				X			
Soil Moisture Active Passive	L-band radar					X		
Sentinel 1	C-band radar							X

Click on the link below for a comprehensive list of **NASA satellites and sensors** for **agricultural applications**: https://arset.gsfc.nasa.gov/sites/default/files/land/20-Ag-Training/NASA_Satellite_Instruments_Relevant_for_Agricultural_Applications.pdf

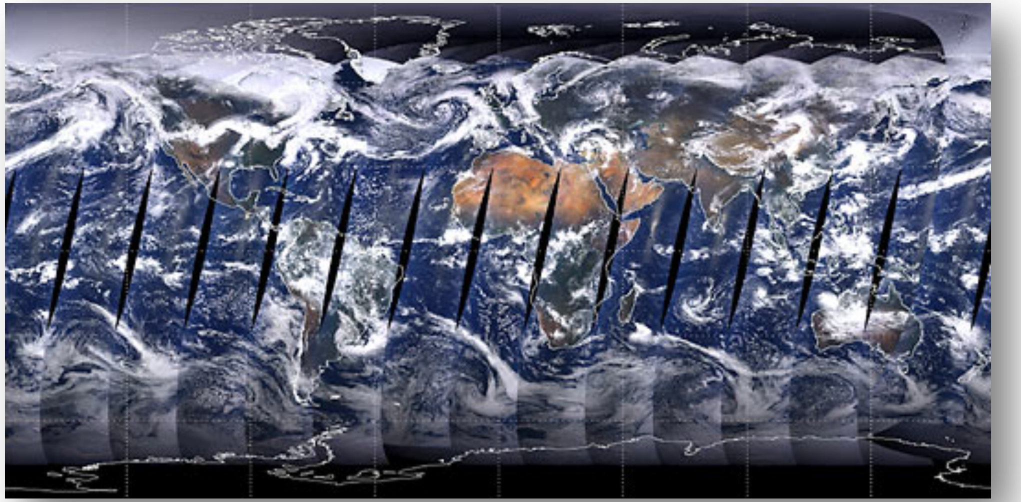
Land Surface Reflectance

- Provide an estimate of surface spectral reflectance as measured at ground level by accounting for atmospheric effects like aerosol scattering and thin clouds
- Useful for measuring the greenness of vegetation, which can then be used to determine phenological transition dates including start of season, peak period, and end of season
- Input for generation of several land products: Vegetation Indices (VIs), Bidirectional Reflectance Distribution Function (BRDF), thermal anomaly, snow/ice, Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), and Leaf Area Index (LAI)

Three moments in a tumultuous year for farming north of St. Louis, MO, as seen in NASA-USGS Landsat 8 data. On the left is May 7, 2019, as heavy rains delayed planting for many farms. Sept 12, 2019, in the middle, shows bright green signifying growing vegetation, although with a fair amount of brown, bare fields. On the right, Oct. 14, 2019, the light brown indicates harvested fields while darker brown are fields that have not been seeded or fallow all summer.
Image Credit: NASA-USGS Landsat

Satellites & Sensors for Land Surface Reflectance - MODIS

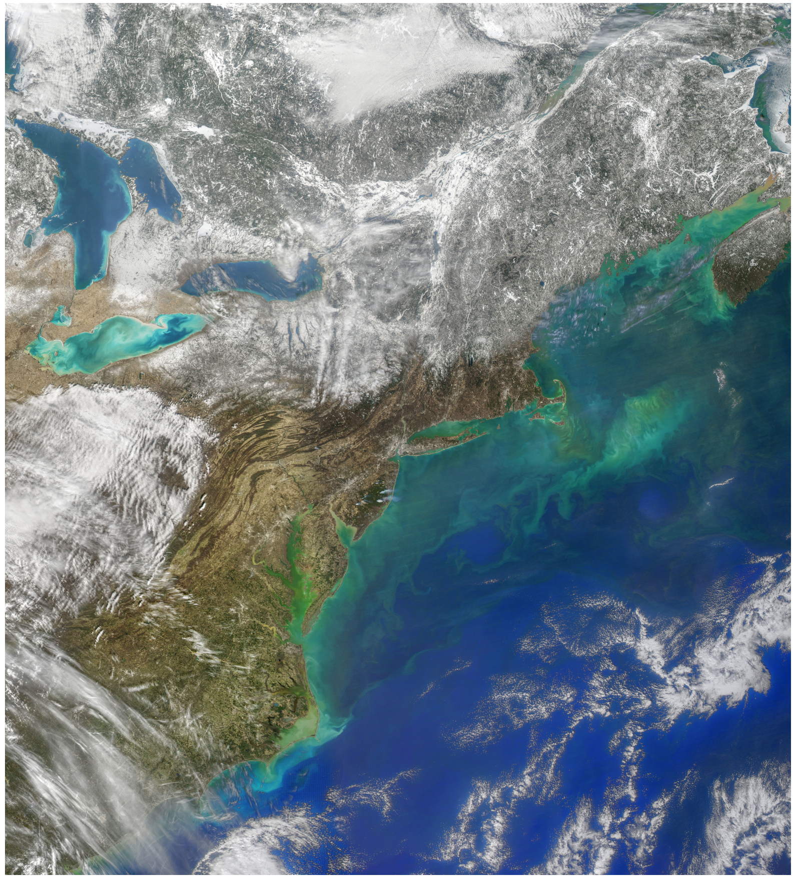
- Moderate Resolution Imaging Spectroradiometer (MODIS)
  - MODIS instrument on two NASA platforms:
    - Terra (1999-present)
    - Aqua (2002-present)
  - Spatial Resolution: 250 m, 500 m, 1 km
  - Spectral Resolution: 36 bands, ranging in wavelengths from 0.4 µm to 14.4 µm
  - Temporal Resolution: Daily, 8-day, 16-day, monthly, yearly
  - 2000 – Present
  - Global coverage with orbital gaps in the tropics



MODIS Orbital Coverage
Image Credit: NASA

Satellites & Sensors for Land Surface Reflectance - MODIS

- Moderate Resolution Imaging Spectroradiometer (MODIS)
  - **MOD09**: Level 2 & 3 surface reflectance product name
  - Bands 1 and 2 (250m)
  - Bands 1-7 (500 m)
  - Bands 1-16 (1 km)
- MODIS Surface Reflectance User's Guide
  - http://modis-sr.ltdri.org/guide/MOD09_UserGuide_v1.4.pdf
- Data Acquisition (requires free registration)
  - https://search.earthdata.nasa.gov/search?q=MOD09



MODIS composite of the eastern U.S. captured on February 23, 2020 by NASA's Aqua satellite. Image credit: NASA Earth Observatory

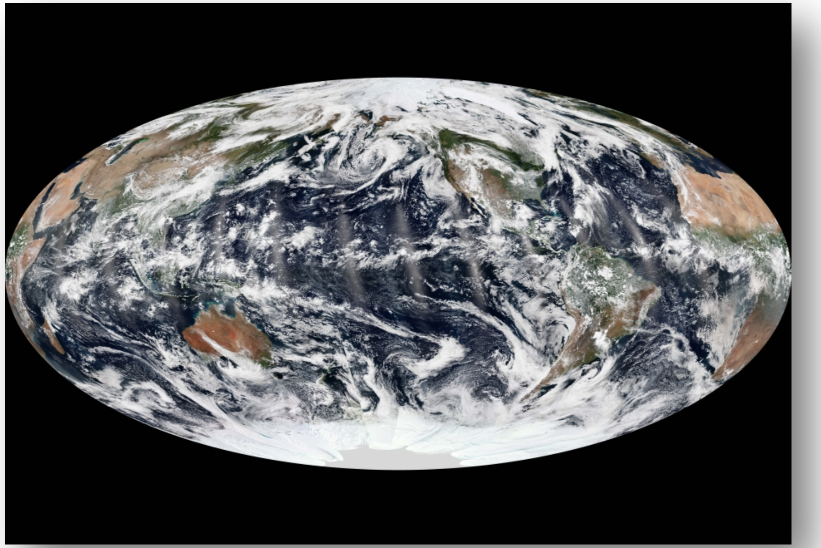
Satellites & Sensors for Land Surface Reflectance - MODIS

MODIS Name	Product Name Short Name	Spatial Resolution (m)	Temporal Resolution
MOD 09	Surface Reflectance	250, 500	Daily, 8-Day
MOD 11	Land Surface Temperature	1000	Daily, 8-Day
MOD 12	Land Cover/Change	500	8-Day, Yearly
MOD 13	Vegetation Indices	250, 500, 1000	8-Day, 16-Day, Monthly
MOD 14	Thermal Anomalies/Fire	1000	Daily, 8-Day
MOD 15	Leaf Area Index/Fraction of Absorbed Photosynthetically Active Radiation (FPAR)	500	4-Day, 8-Day
MOD 16	Evapotranspiration	500	8-Day, Yearly
MOD 17	Primary Production	500	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 land products are available as [Level 2 to 4 products]()

Satellites & Sensors for Land Surface Reflectance - VIIRS

- Visible Infrared Imaging Radiometer Suite (VIIRS)
  - Instrument on two NOAA platforms:
    - Suomi National Polar-orbiting Partnership (Suomi-NPP)
    - NOAA-20
  - Spatial Resolution: 375 m and 750 m
  - Spectral Resolution: 22 bands (0.4 µm – 12.5 µm)
  - Temporal Resolution: Daily, 8-day, 16-day, monthly, yearly
  - 2012 - Present
  - Global Coverage



VIIRS orbital coverage
Image Credit: NASA

Satellites & Sensors for Land Surface Reflectance - VIIRS

- VIIRS builds and expands on the heritage of land science from AVHRR and MODIS
  - **VNP09**: Level 2 & 3 surface reflectance product name
  - Well-calibrated, high quality, multispectral-land surface reflectance product
  - Resampled to 500 m, 1 km, and 0.05 degrees to promote consistency with MODIS products
- VIIRS Surface Reflectance User's Guide:
  https://viirsland.gsfc.nasa.gov/PDF/VIIRS_Surf_Refl_UserGuide_v1.3.pdf
- Data Acquisition (requires free registration)
  - https://search.earthdata.nasa.gov/search?q=VNP09

Differences between MODIS & VIIRS

- Similar but not identical spectral characteristics
- VIIRS has improved spatial resolution at swath edge

- Skakun et al. (2018) Transitioning from MODIS to VIIRS: An Analysis of Inter-Consistency of NDVI Data Sets for Agricultural Monitoring DOI: [10.1080/01431161.2017.1395970](https://doi.org/10.1080/01431161.2017.1395970)

VIIRS Band	Spectral Range (µm)	Nadir HSR (m)	MODIS Band(s)	Spectral Range (µm)	Nadir HSR (m)
DNB	0.500 – 0.900				
M1	0.402 – 0.422	750	**8**	0.405 – 0.420	1000
M2	0.436 – 0.454	750	**9**	0.438 – 0.448	1000
M3	0.478 – 0.498	750	**3** **10**	0.459 – 0.479 0.483 – 0.493	500 10000
M4	0.545 – 0.565	750	**4** **12**	0.545 – 0.565 0.546 – 0.556	500 1000
I1	0.600 – 0.680	375	**1**	0.620 – 0.670	250
M5	0.662 – 0.682	750	**13** **14**	0.662 – 0.672 0.673 – 0.683	1000 1000
M6	0.739 – 0.754	750	**15**	0.743 – 0.753	1000
I2	0.846 – 0.885	375	**2**	0.841 – 0.876	250
M7	0.846 – 0.885	750	**16** **2**	0.862 – 0.877 0.841 – 0.876	1000 250
M8	1.230 – 1.250	750	**5**	SAME	500
M9	1.371 – 1.386	750	**26**	1.360 – 1.390	1000
I3	1.580 – 1.640	375	**6**	1.628 – 1.652	500
M10	1.580 – 1.640	750	**6**	1.628 – 1.652	500
M11	2.225 – 2.275	750	**7**	2.105 – 2.155	500
I4	3.550 – 3.930	375	**20**	3.660 – 3.840	1000
M12	3.660 – 3.840	750	**20**	SAME	1000
M13	3.973 – 4.128	750	**21** **22**	3.929 – 3.989 3.929 – 3.989	1000 1000
M14	8.400 – 8.700	750	**29**	SAME	1000
M15	10.263 -- 11.263	750	**31**	10.780 – 11.280	1000
I5	10.500 – 12.400	375	**31** **32**	10.780 – 11.280 11.770 – 12.270	1000 1000
M16	11.538 – 12.488	750	**32**	11.770 – 12.270	1000

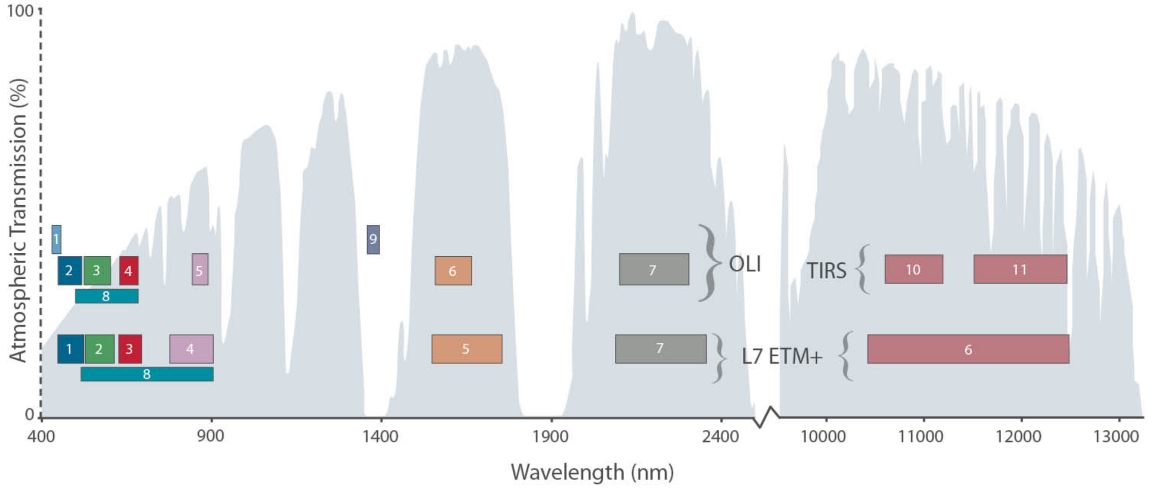
Satellites & Sensors for Land Surface Reflectance – OLI

- Landsat 8 launched on February 11, 2013
  - Instruments:
    - Operational Land Imager (OLI)
    - Thermal Infrared Sensor (TIRS)
  - Landsat data have been produced, archived, and distributed by the U.S. Geological Survey (USGS) since 1972
  - Builds on ~50 years of the Landsat program, offering the longest continuous global record of the Earth's surface
  - https://landsat.gsfc.nasa.gov/landsat-data-continuity-mission/

Landsat 8 OLI image captured on September 9, 2013 showing the border between Kazakhstan and China
Image Credit: NASA Earth Observatory

Satellites & Sensors for Land Surface Reflectance – OLI

- Landsat 8 Operational Land Imager (OLI)
  - Spatial Resolution: 30 m
  - Spectral Resolution: 9 bands ranging in wavelengths from 430 nm to 2290 nm
  - Temporal Resolution: 16 days
  - 2013 – Present
  - Global Coverage
- Data Acquisition (requires free registration)
  - https://earthexplorer.usgs.gov/



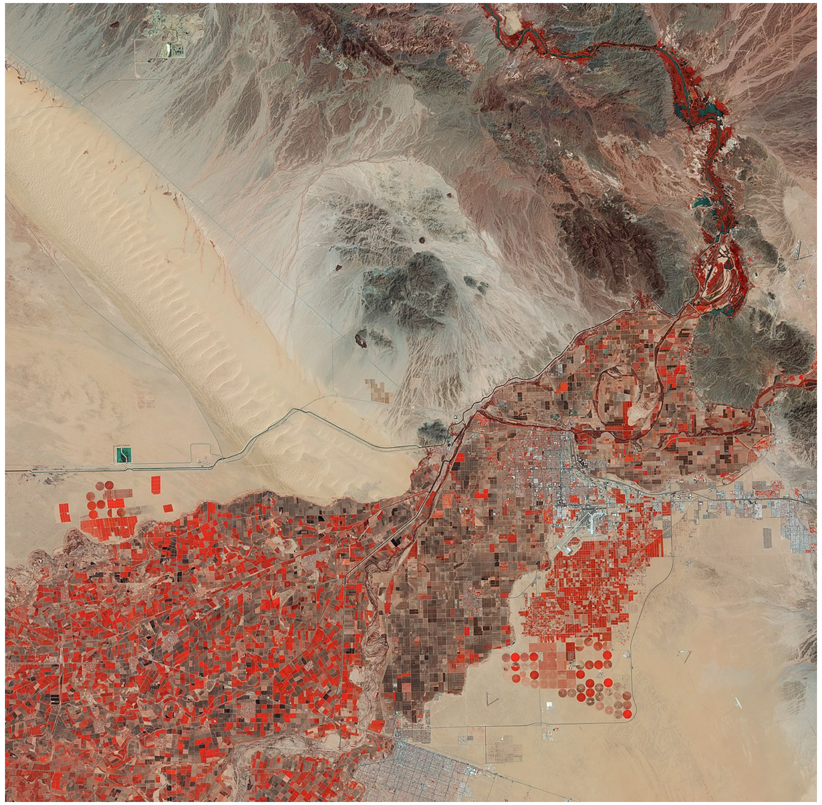
Satellites & Sensors for Land Surface Reflectance – MSI

- Sentinel 2A launched on June 23, 2015
- Sentinel 2B launched on March 7, 2017
  - Constellation of two polar-orbiting satellites in the same sun-synchronous orbit, phased at 180° to each other
  - Collaboration between the European Commission, European Space Agency (ESA), and European Union (EU)
  - Sensor: Multi-Spectral Instrument (MSI)
  - https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2

Sentinel 2 MSI image captured on June 30, 2018 showing the Noordoostpolder municipality in the central Netherlands
Image Credit: Copernicus, ESA

Satellites & Sensors for Land Surface Reflectance – MSI

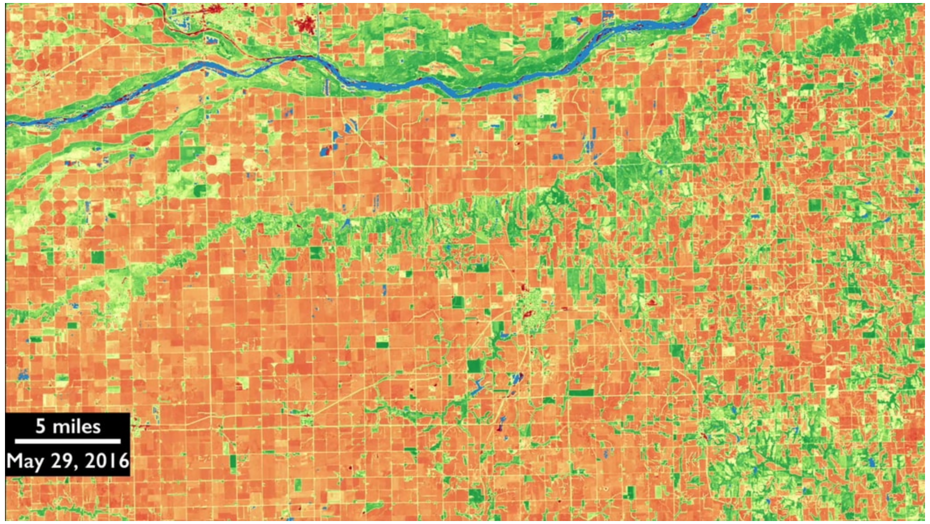
- Multi-Spectral Instrument (MSI)
  - Spatial Resolution: 10 m (VNIR), 20 m (red edge, SWIR), & 60 m (atmospheric bands)
  - Spectral Resolution: 13 bands from VNIR to SWIR in wavelengths from 0.44 µm to 2.2 µm
  - Temporal Resolution: 5 days
  - 2015 – Present
  - Level-2A product provides orthorectified Bottom-Of-Atmosphere (BOA) reflectance
  - Global Coverage
- Data Acquisition (requires free registration)
  - https://scihub.copernicus.eu/



Sentinel 2 MSI image captured on August 20, 2015 at U.S.-Mexico border near Yuma, AZ
Image credit: Copernicus, ESA

Satellites & Sensors for Land Surface Reflectance – HLS

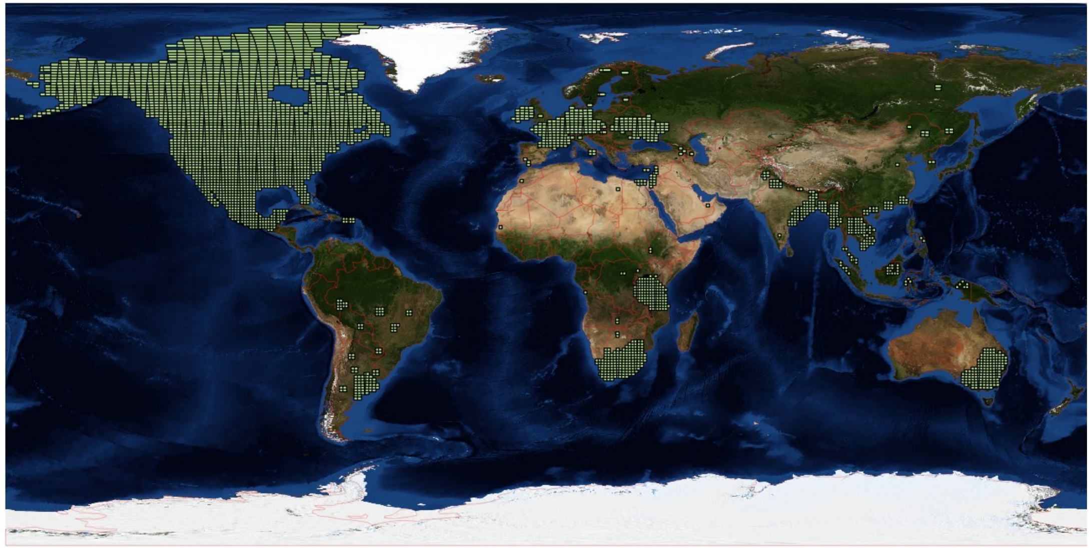
- Harmonized Landsat and Sentinel-2 (HLS)
  - Combines the land surface observations of OLI & MSI into a single data set
  - Observations at 30-meter resolution every 2-3 days
  - Gridded to a common pixel resolution, map projection, and tile
  - Atmospherically corrected and cloud masked
  - Normalized to a common nadir view geometry via BRDF estimation
  - https://hls.gsfc.nasa.gov/



HLS image captured on May 29, 2016 near Cunningham, Kansas. Red is bare soil and green indicates healthy, growing vegetation. Image Credit: NASA's Goddard Space Flight Center

Satellites & Sensors for Land Surface Reflectance – HLS

- All of North America and some globally distributed sites are processed in v1.4
- Harmonized Landsat Sentinel-2 (HLS) Product User's Guide v1.4:
  - https://hls.gsfc.nasa.gov/wp-content/uploads/2019/01/HLS.v1.4.UserGuide_draft_ver3.1.pdf
  - S30 and L30 products provide 30 m Nadir BRDF-Adjusted Reflectance (NBAR)
  - Allows for monitoring phenology, crop condition, and management
- Data Acquisition
  - https://hls.gsfc.nasa.gov/data/



Current coverage of HLS tiles
Image Credit: NASA

Evapotranspiration

- Sum of evaporation from the land surface plus transpiration in vegetation
- Highly variable in space and time
- Critical component of the water and energy balance of climate-soil-vegetation interactions
- Extremely useful in monitoring and assessing water availability, drought conditions, and crop production
- Remote sensing has long been recognized as the most feasible means to provide spatially distributed regional ET information over land surfaces
- Can not be measured directly with satellite instruments. Modeled outputs are dependent on many variables:
  - Land surface temperature, air temperature, solar radiation, humidity, albedo, soil conditions, and vegetation cover
- https://arset.gsfc.nasa.gov/sites/default/files/water/ET-SMAP/week1-v2.pdf

Evapotranspiration

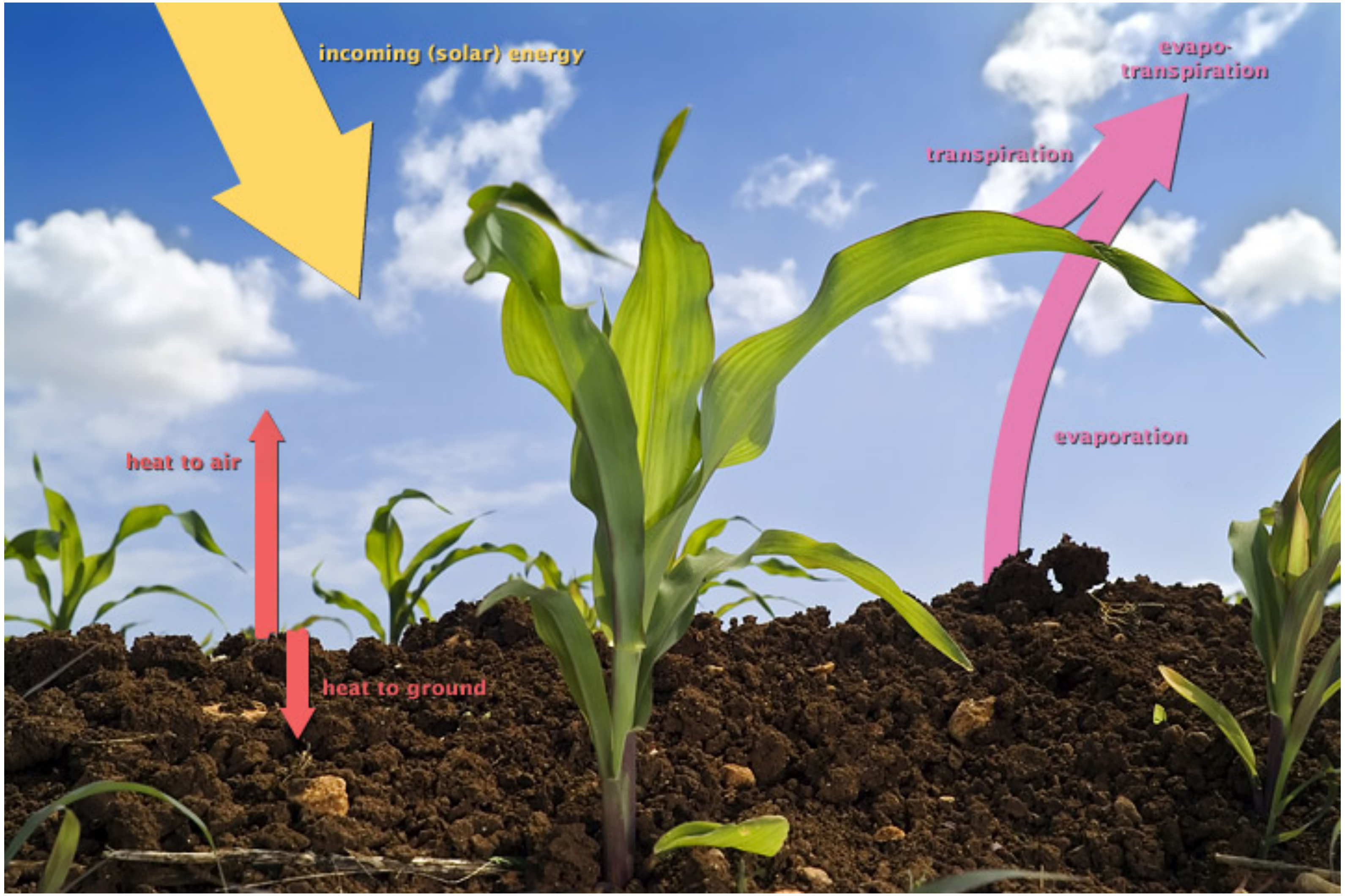
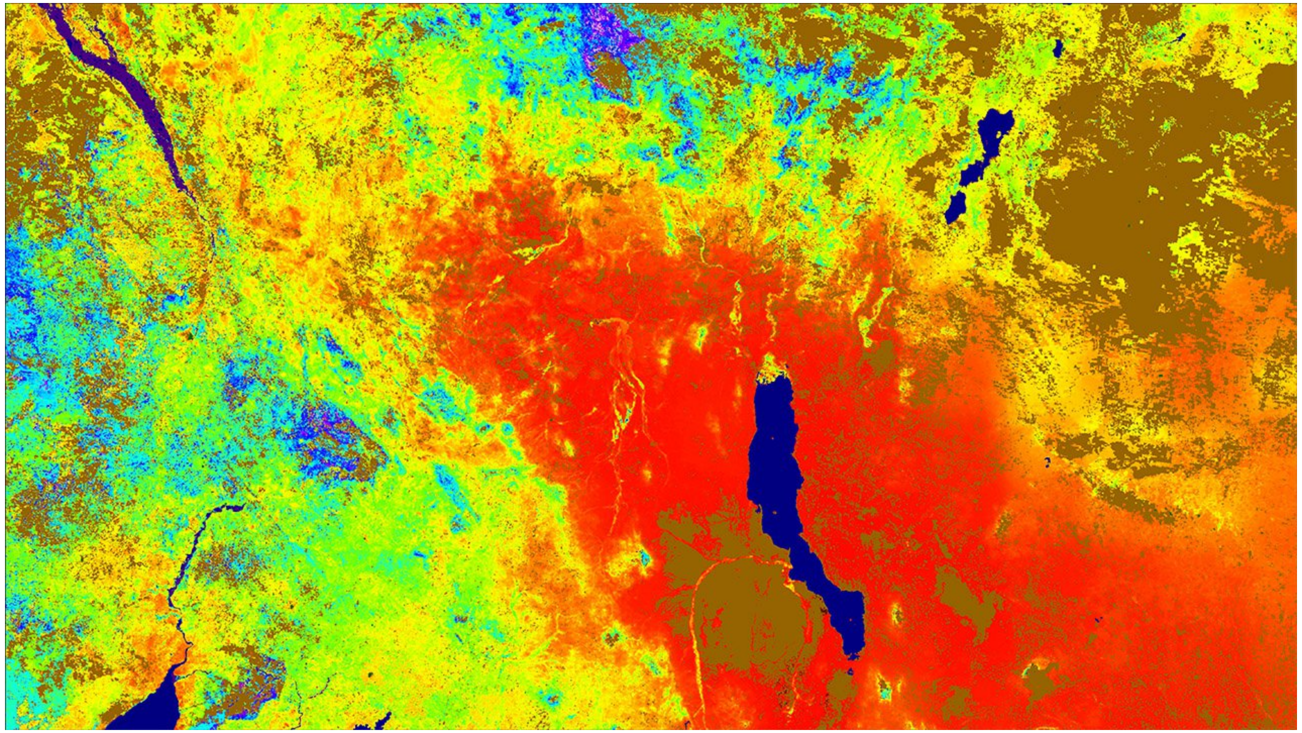


Image Credit: NASA

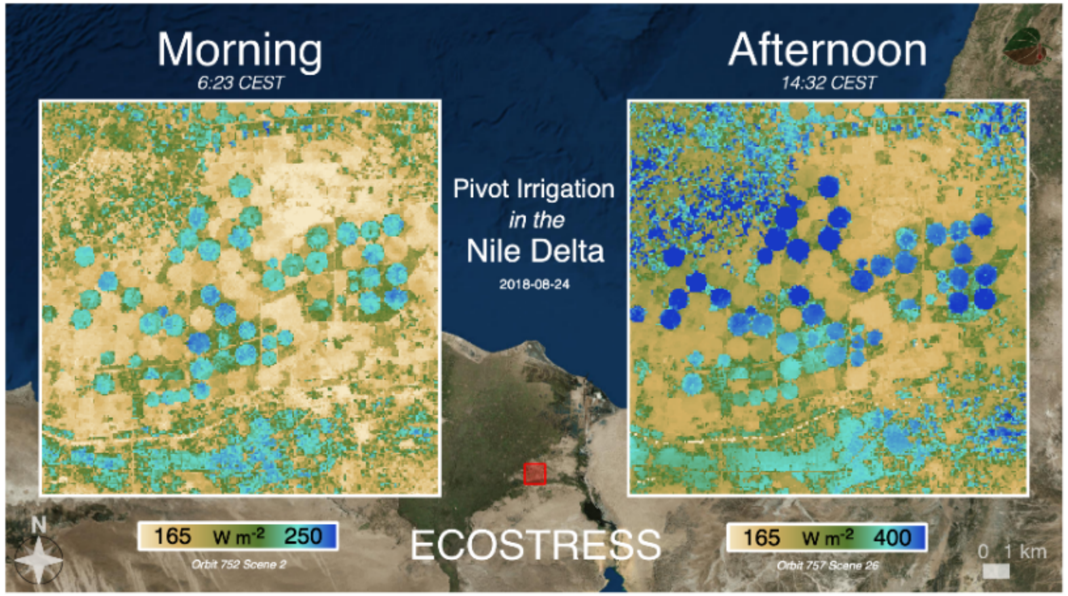
Satellites & Sensors for Evapotranspiration - MODIS

- Moderate Resolution Imaging Spectroradiometer (MODIS)
  - **MOD16**: Level 4 Evapotranspiration/Latent Heat Flux
  - 8-day, yearly intervals
  - Spatial Resolution: 500 m
  - 2001 – Present
  - Global Coverage
  - MOD16A2/A3 User's guide
  - Data acquisition: https://search.earthdata.nasa.gov/search?q=MOD16



Satellites & Sensors for Evapotranspiration - ECOSTRESS

- ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)
  - Instrument mounted to the International Space Station (ISS)
  - Measures agricultural water consumption over continental U.S. (CONUS) at spatio-temporal scales for drought estimation
  - Coverage: CONUS, key biomes/ agricultural zones, selected FLUXNET sites
  - https://arset.gsfc.nasa.gov/land/webinars/ECOSTRESS



NASA's ECOSTRESS imaged the Nile Delta, Egypt on August 24, 2018. ECOSTRESS captured changes in evapotranspiration from agricultural fields within the same day. The image on the left is from 6:23 CEST, and the image on the right is from 14:32 CEST. Much more ET is shown in the afternoon image (blue colors), though there are larger differences between the fields than in the morning.
Credit: Simon Hook, NASA

Satellites & Sensors for Evapotranspiration - ECOSTRESS

- ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)
  - July 09, 2018 – Present
  - Spatial Resolution: 70 m
  - Spectral Resolution: 8 – 12.5 μm
  - Temporal Resolution: Variable, depending on the ISS
  - Data Acquisition: https://search.earthdata.nasa.gov/search?q=ECO3ET
  - E-Learning: https://lpdaac.usgs.gov/resources/e-learning/#ecostress

Satellites & Sensors for Evapotranspiration - LDAS

- Land Data Assimilation System (LDAS)
- Provides model-based ET data of which there is a global collection (GLDAS) and a North American collection (NLDAS)
- Integrates satellite and ground observations within sophisticated numerical models based on water and energy balance methods
- Spatial Resolution: 0.25-degree and 1-degree
- Temporal Resolution: 3-hourly, daily, monthly
  - 1948 – Present
  - Data Acquisition: https://disc.gsfc.nasa.gov/datasets?keywords=GLDAS&page=1

Land Surface Temperature

- Land Surface Temperature (LST) products show the temperature of the land surface in Kelvin (K)
- Differs from air temperature measurements as it provides the temperature of whatever is on the surface of the Earth (e.g. bare sand, ice- and snow-covered area, leaf-covered tree canopy, roads, etc.)
- Useful for monitoring changes in weather and climate patterns
- Used in agriculture and water resource management to allow farmers and decision makers to evaluate water requirements

Satellites & Sensors for Land Surface Temperature - MODIS

- Moderate Resolution Imaging Spectroradiometer (MODIS)
  - MOD11 Land Surface Temperature and Emissivity (LST&E) Level 3 products
  - Available from both Terra (10:30 am) & Aqua (1:30 pm) satellites
  - Temporal Resolution: Daily, 8-day, or monthly
  - Spatial Resolution: 1 km, 6 km, 0.05 degrees
  - 2000 – Present
  - Global Coverage
  - MOD11 User's guide
  - Data Acquisition: https://search.earthdata.nasa.gov/search?q=MOD11

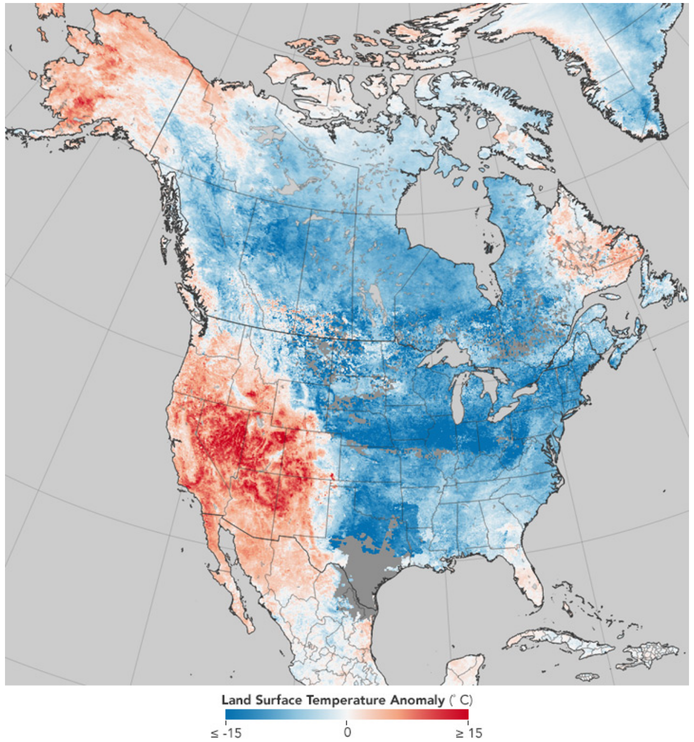


Image Credit: NASA Earth Observatory

Satellites & Sensors for Land Surface Temperature - VIIRS

- Visible Infrared Imaging Radiometer Suite (VIIRS)
  - **VNP21** Land Surface Temperature and Emissivity (LST&E) Level 3 products
  - Temporal Resolution: Daily, 8-day
  - Spatial Resolution: 750 m, 1 km
  - 2012 – Present
  - Global Coverage
  - MOD16A2 User's guide
  - Data Acquisition: https://search.earthdata.nasa.gov/search?q=VNP21&fi=VIIRS

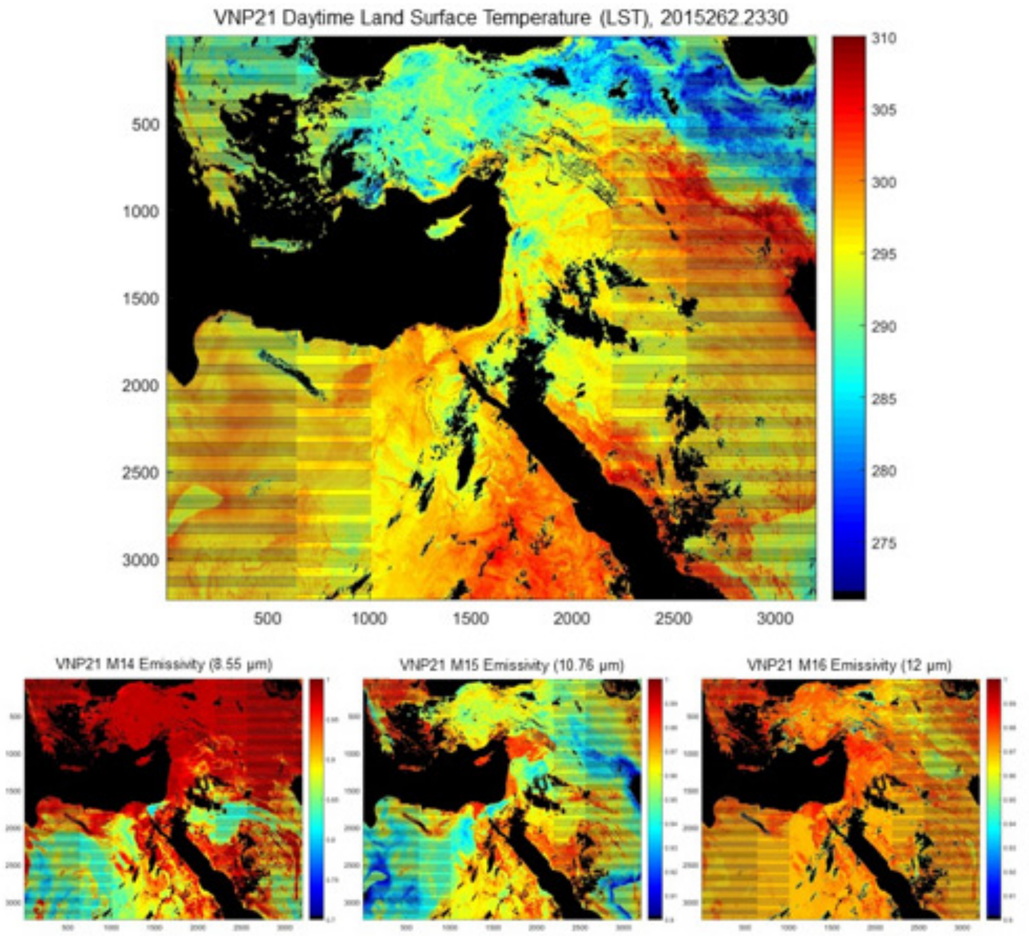


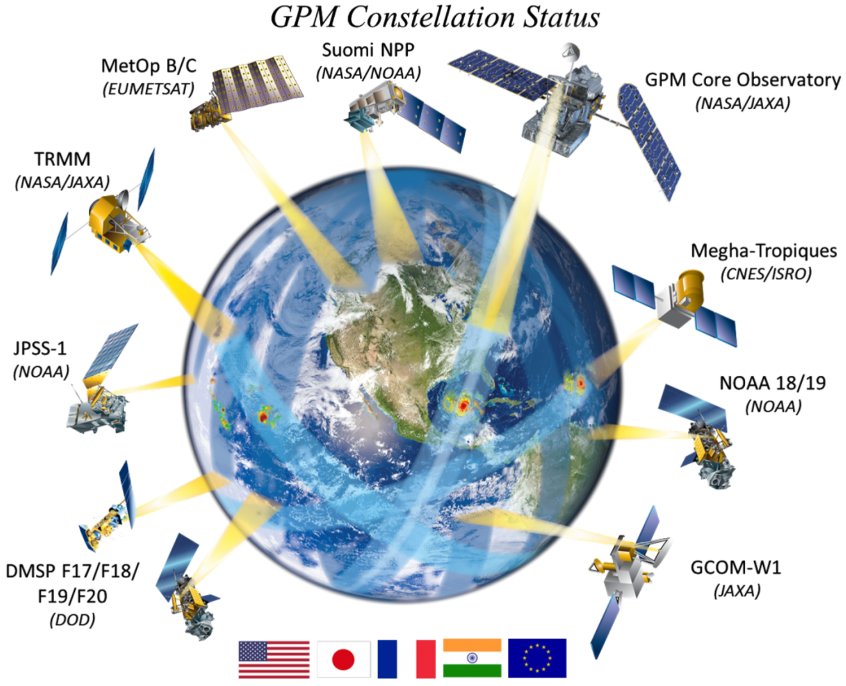
Image Credit: NASA

Precipitation

- Precipitation is a key component of the water cycle, and difficult to measure since rain and snow vary greatly in both space and time
- Satellites provide frequent and accurate observations and measurements of rain and snow around the planet, especially where ground-based data are sparse
- Radar/radiometer estimates measure the intensity and variability of latent heating structures of precipitation systems
- Agricultural community needs to know the timing and amount of rain or snow to forecast crop yields as well as freshwater shortages affecting irrigation and production

Satellites & Sensors for Precipitation - GPM

- Global Precipitation Measurement (GPM) mission
- Joint mission between NASA & JAXA
- Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (IMERG) product
- 0.1° x 0.1° grid (60°S to 60°N)
- 2000 – Present
- Level 3 products for half-hourly, daily, monthly data
- Data Access:
  - https://search.earthdata.nasa.gov/search?q=IMERG
  - For more information on IMERGv6 and how to calculate precipitation anomalies, refer to the ARSET training: https://arset.gsfc.nasa.gov/water/webinars/IMERG-2020



Satellites & Sensors for Precipitation - CHIRPS

- Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)
  - Rainfall estimates from **rain gauge** and **satellite observations**
  - Developed by Climate Hazards Center (UC Santa Barbara, California)
  - Incorporates in-house climatology, 0.05° resolution Infrared satellite data, and in-situ station data
  - 0.05° x 0.05° grid (50°S-50°N)
  - 1981 – Near-Present
- Data Access:
  - https://www.chc.ucsb.edu/data/chirps

Satellites & Sensors for Soil Moisture - SMAP

- Soil Moisture Active Passive (SMAP)
- L-band passive radiometer receives energy in a narrow microwave band (1.41 Ghz)
- **Level 4 products** assimilate SMAP L-band brightness temperature data into a land surface model generating root zone and surface soil moisture
- Spatial Resolution: 9 km
- Temporal Resolution: 3-hourly, Daily
- Data Access:
  - National Snow & Ice Data Center
  - https://nsidc.org/data/smap/smap-data.html

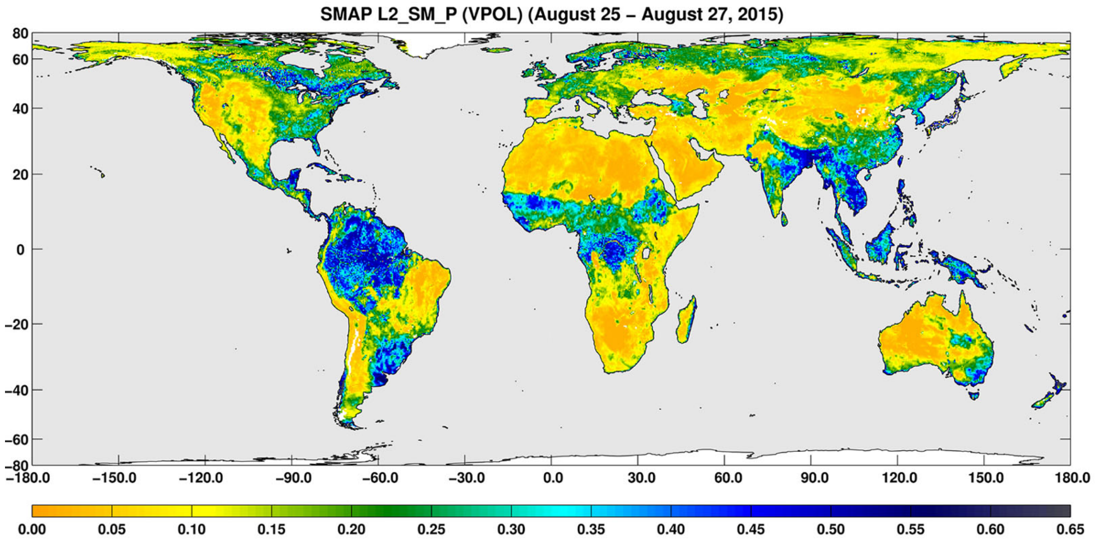


Image Credit: NASA

We'll be discussing more about SMAP soil moisture in the second part of the training.

Satellites & Sensors for Soil Moisture - LDAS

- Land Data Assimilation Systems (LDAS)
- Uses numerical models to integrate satellite information with ground-based data
- Output estimates of soil moisture, temperature, and evapotranspiration
- https://ldas.gsfc.nasa.gov/

- **We'll be discussing more about LDAS soil moisture in the second part of the training.**

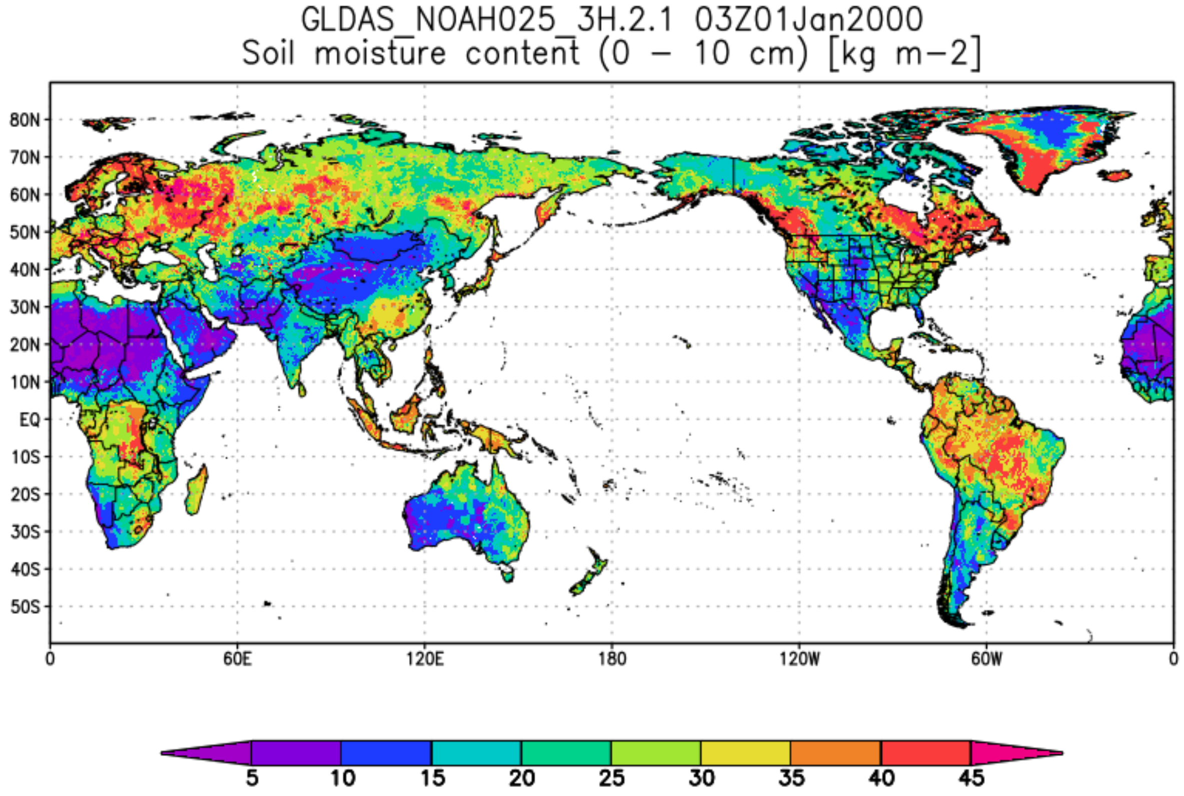
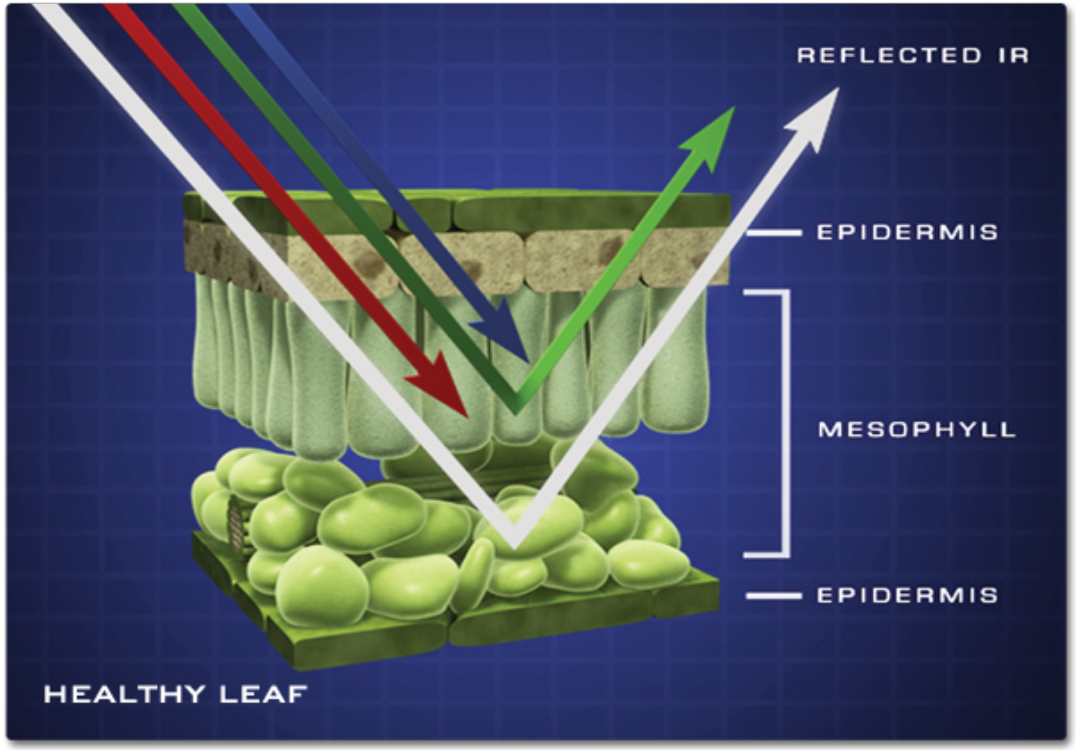


Image Credit: NASA

Satellites & Sensors for Vegetation Greenness

- Healthy vegetation absorbs blue and red light to fuel photosynthesis and create chlorophyll.
- A plant with more chlorophyll will reflect more near-infrared energy than an unhealthy plant. Thus, analyzing a plant's spectrum of both absorption and reflection in visible and in near-infrared wavelengths can provide information about the plant's health and productivity.
- Reflected near-infrared radiation can be sensed by satellites, allowing scientists to study vegetation from space.

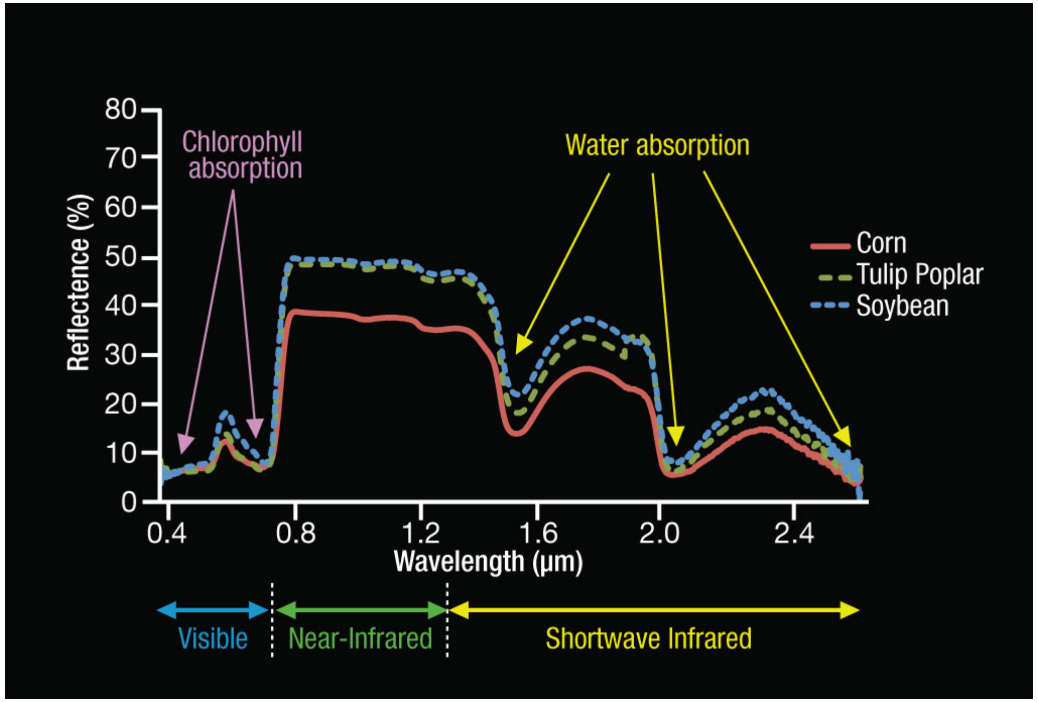


Credit: Jeff Carns, NASA

Satellites & Sensors for Vegetation Greenness - NDVI

Normalized Difference Vegetation Index (NDVI)

- Based on the relationship between red and near-infrared wavelengths
- Advantages:
  - Efficient and simple index to identify vegetated areas and their condition
  - Reduces sun-angle, shadow, and topographic variation effects
  - Enables large-scale vegetation monitoring, allowing comparison of different regions through time

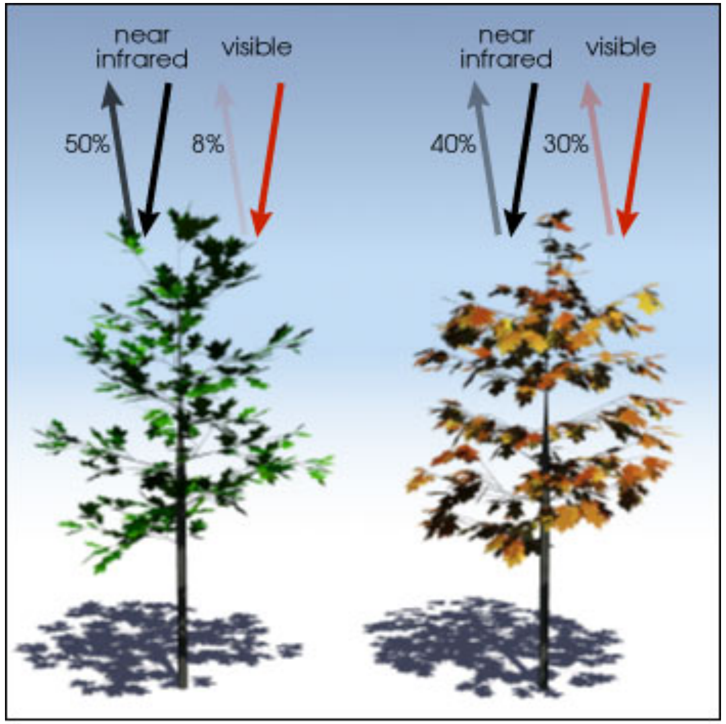


Credit: Eric Brown de Colstoun, NASA

Satellites & Sensors for Vegetation Greenness - NDVI

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

- Theoretically, values range from -1.0 to 1.0
  - Typical range of NDVI measured from Earth's surface is between about −0.1 for non-vegetated surfaces and as high as 0.9 for dense green vegetation
  - Increases with increasing green biomass, changes seasonally, and responds to climatic conditions



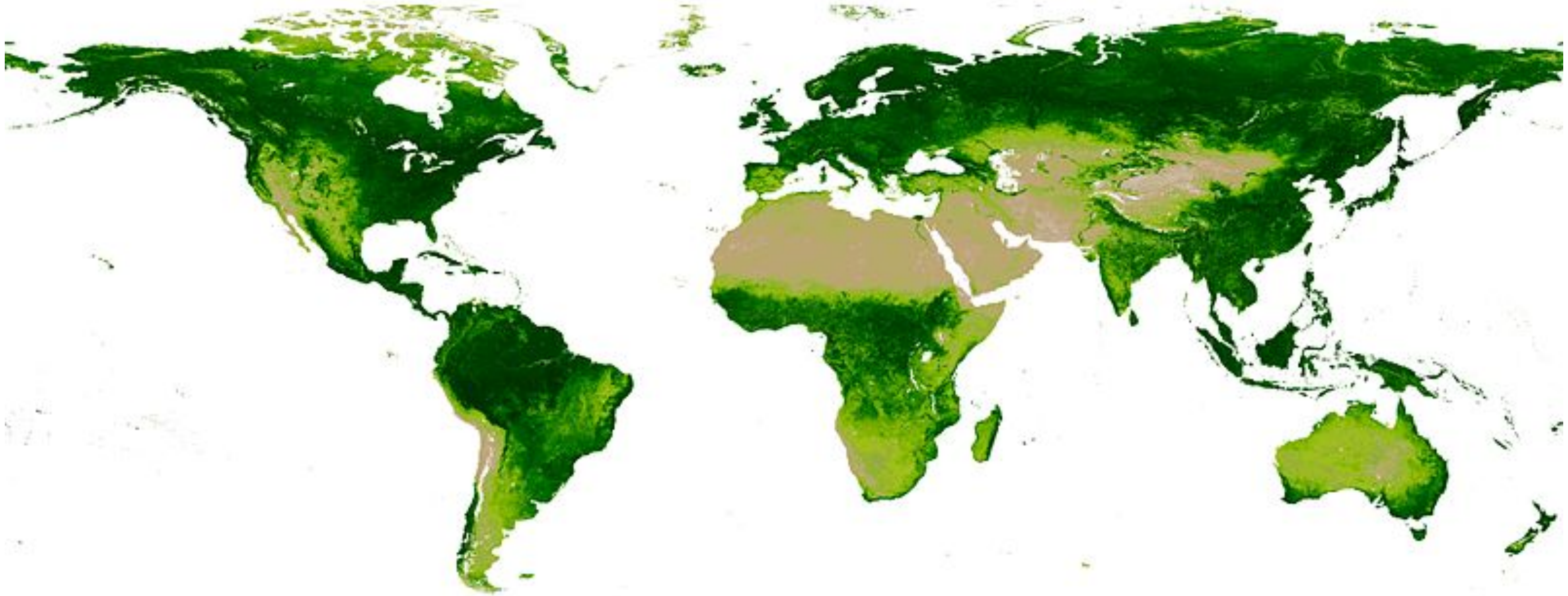
$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Example of NDVI being calculated for healthy green vegetation and senescing vegetation
Credit: Robert Simmon, NASA

Satellites & Sensors for Vegetation Greenness - NDVI

NDVI Applications:

- Phenology
- Drought Indicator
- Vegetation Health
- Carbon Monitoring
- Leaf Area Index (LAI)



World NDVI, created from MODIS MYD13C1 dataset, 2013
Credit: Ivan Shmakov

Satellites & Sensors for Vegetation Greenness - MODIS

- Moderate Resolution Imaging Spectroradiometer (MODIS)
  - **MOD13**: Level 3 products for Vegetation Indices
  - Two primary vegetation layers retrieved from daily, atmosphere-corrected, bidirectional surface reflectance:
    - Normalized Difference Vegetation Index (NDVI)
    - Enhanced Vegetation Index (EVI)
  - Spatial Resolution: 250 m, 500 m, 1 km
  - Temporal Resolution: 8-day, 16-day, monthly
  - 2000 – Present
- MODIS Vegetation Index User's Guide
  - Data Acquisition (requires free registration) https://search.earthdata.nasa.gov/search?q=mod13

Satellites & Sensors for Vegetation Greenness - VIIRS

- Visible Infrared Imaging Radiometer Suite (VIIRS)
  - **VNP13**: Level 3 products for Vegetation Indices
  - Provides vegetation indices by a process of selecting the best available pixel over a 16-day and monthly acquisition period
  - Three primary vegetation layers:
    - Normalized Difference Vegetation Index (NDVI)
    - Enhanced Vegetation Index (EVI) & Enhanced Vegetation Index-2 (EVI2)
  - Spatial Resolution: 500 m, 1 km, 0.05 degrees
  - Temporal Resolution: 16-day, monthly (2012 – Present)
- VIIRS Vegetation Index User's Guide
  - Data Acquisition (requires free registration)
    https://search.earthdata.nasa.gov/search?q=VNP13

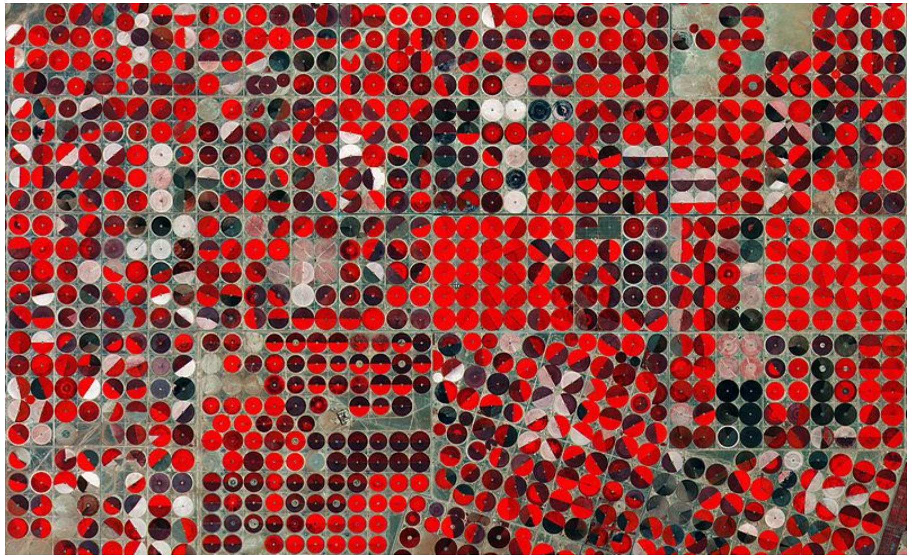
Satellites & Sensors for Vegetation Greenness - OLI

- Landsat 8 Operational Land Imager (OLI)
  - Landsat Surface Reflectance-derived NDVI are produced on-demand from USGS EROS: https://espa.cr.usgs.gov/
  - It can also be calculated using QGIS (see below)
  - Spatial Resolution: 30 m
  - Temporal Resolution: 16 days
  - 2013 – Present
  - Global Coverage
- Learn how to acquire, use, and derive NDVI from the following ARSET training: https://arset.gsfc.nasa.gov/land/webinars/advancedNDVI

Credit: NASA

Satellites & Sensors for Vegetation Greenness - MSI

- Sentinel 2 Multi-Spectral Instrument (MSI)
  - Sentinel 2 MSI Surface Reflectance-derived NDVI can be calculated using QGIS, SNAP, or Google Earth Engine
  - Spatial Resolution: 10 m
  - Temporal Resolution: 5 days
  - 2015 – Present
  - Global Coverage
- Data Acquisition (requires free registration)
  - https://scihub.copernicus.eu/



Sentinel-2A satellite shows agricultural structures near Tubarjal, Saudi Arabia. Circles come from a central-pivot irrigation system.
Image Credit: ESA

Synthetic Aperture Radar (SAR)

Advantages and Disadvantages of Radar Over Optical Remote Sensing

Advantages

- Nearly all-weather capability
- Day or night capability
- Penetration through the vegetation canopy
- Penetration through the soil
- Minimal atmospheric effects
- Sensitivity to dielectric properties (liquid vs. frozen water)
- Sensitivity to structure

Disadvantages

- Information content is different than optical and sometimes difficult to interpret
- Speckle effects (graininess in the image)
- Effects of topography

Land Cover Mapping: Optical vs Radar

Optical

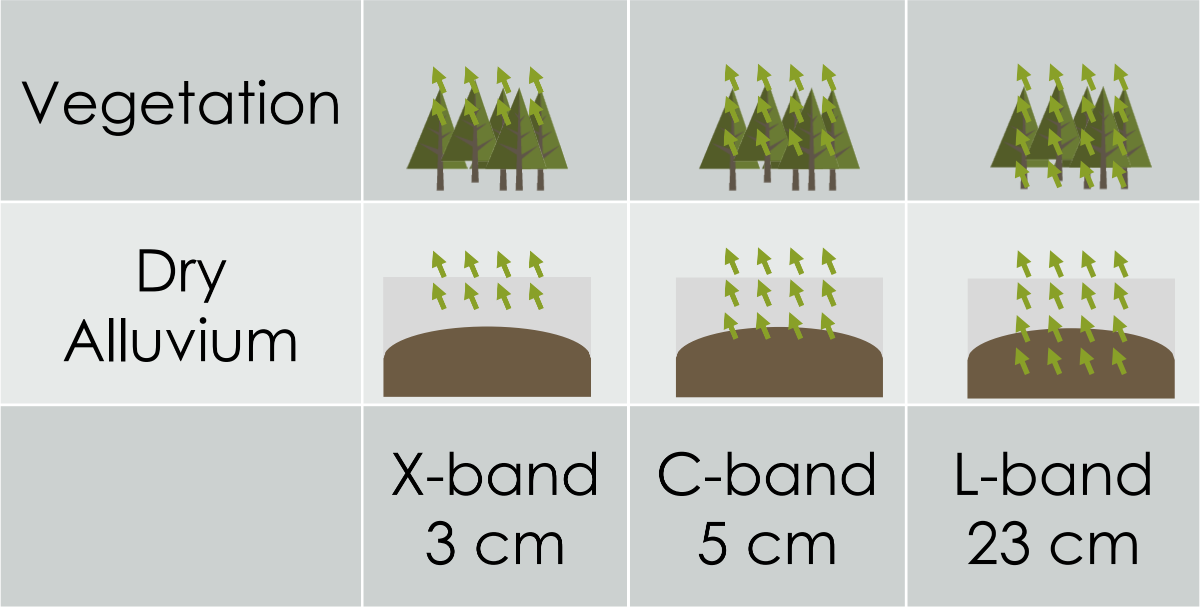
- Energy reflected by vegetation is dependent on leaf structure, pigmentation, and moisture.
- Products are available from visible to infrared wavelengths, consisting of several bands of data.
- Optical sensors only see surface tops because the canopy blocks the understory, limiting the inferences of land cover and land use to only when these are correlated well with the characteristics of top layers.

Radar

- Microwave energy scattered by vegetation depends on the structure (size, density, orientation) and dielectric properties of the target.
- Radar signals are typically only at a single wavelength for each sensor.
- The signal can penetrate through the canopy (wavelength dependent), providing information on soil conditions or inundation state.

Joshi et al., Remote Sens. 2016, 8(1), 70; https://doi.org/10.3390/rs8010070

Penetration as a Function of Wavelength



- Penetration is the **primary factor** in wavelength selection
- Generally, the longer the wavelength, the greater the penetration into the target

Frequency Band	Application Example
VHF	Foliage & Ground Penetration, Biomass
P-Band	Biomass, Soil Moisture, Penetration
L-Band	Agriculture, Forestry, Soil Moisture
C-Band	Ocean, Agriculture
X-band	Agriculture, Ocean, High-Resolution Radar
Ku-Band	Glaciology (snow cover mapping)
Ka-Band	High-Resolution Radar

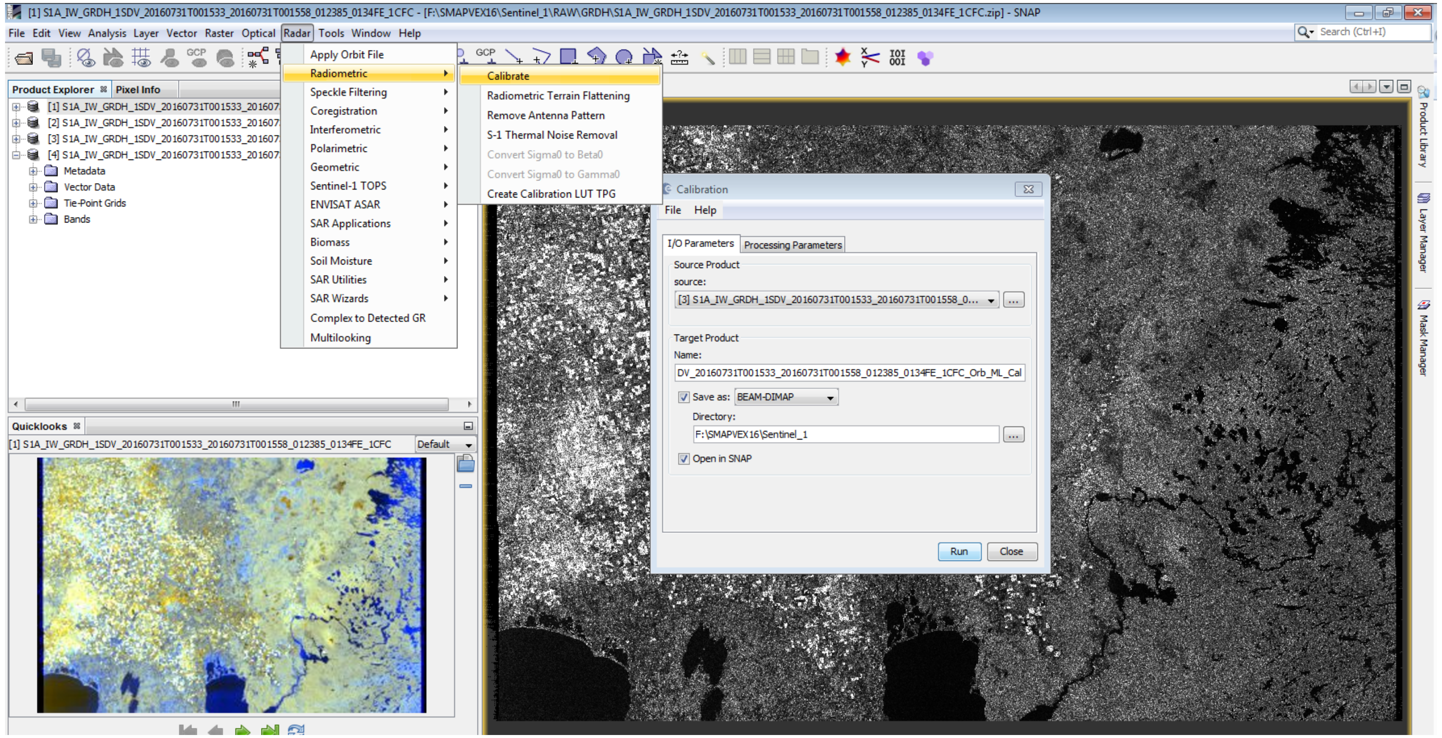
Sentinel-1

- Sentinel-1 Mission: https://sentinel.esa.int/web/sentinel/missions/sentinel-1
- Constellation of two polar-orbiting satellites
- C-band Synthetic Aperture Radar (C-SAR)
- Temporal Resolution: 12 days
- Dual Polarization: VV+VH or HH+HV
- 2014 – Present
- Data Acquisition (requires free registration)
  - https://search.asf.alaska.edu/#/
  - https://scihub.copernicus.eu/
- For more information refer to these ARSET trainings:
  - Introduction to Synthetic Aperture Radar
  - Radar Remote Sensing for Land, Water, & Disaster Applications

Sentinel-1 image taken over the Dutch province of Flevoland from three radar acquisitions taken about two months apart (2018) to show change in crop and land conditions over time.
Image Credit: ESA

Sentinel-1 Toolbox

- A free and open source software developed by ESA for processing and analyzing radar images from Sentinel-1 and other satellites
- It can be accessed through the following site: http://step.esa.int/main/download/
- It includes the following tools
  - Calibration
  - Speckle Noise
  - Terrain Correction
  - Mosaic Production
  - Polarimetry
  - Interferometry
  - Classification



Caveats and Limitations

Limitations of Satellite Data

- It is difficult to obtain high spectral, spatial, and temporal resolution with the same instrument.
- Optical sensors cannot penetrate clouds or vegetative cover, which can lead to data gaps or a decrease in data utility.
- Spatial Resolution: While coarse resolution data (MODIS & VIIRS) provides a synoptic view, the spatial resolution is too coarse for field-level assessments.
- Temporal Resolution: Many satellites only pass over the same spot on Earth every 3-5 days and sometimes as seldom as every 16+ days.
- Spectral Resolution: Multispectral instruments observe reflected and emitted light in broad wavelength ranges for a particular band, with a limited number of bands.
- Large amounts of data exists in various file formats, file sizes, and from multiple sources
- Knowledge of data and tools is required to work with satellite data.

NASA's Food Security & Agriculture Program
NASA HARVEST

A multi-sectoral Consortium enabling and advancing awareness, use, and adoption of satellite Earth observations by public & private organizations to benefit food security and agriculture in the US and worldwide

- Diverse Consortium of >45 members from public, private, NGO, intergovernmental, & humanitarian sectors
- Driven by stakeholder and end-user needs
- Focused on operational R&D and transition
- Demonstrating socioeconomic benefits of EO for agriculture and food security
- NASA's contribution to GEOGLAM
- In close partnership with NASA Food Security Office
- Established Nov. 2017

PI: Dr. Inbal Becker-Reshef
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For more info: www.harvest.org
Follow us on Twitter: @NASAHarvest

This project is funded by NASA under grant no. 80NSSC17K0625

Strong Program Management

Impact Areas

We aim to improve…

- Agricultural Land Use
- Agricultural Sustainability
- Agricultural Productivity

Products & Method Areas

… by advancing…

- Crop Mapping
- Crop Statistics
- Crop Yield
- Crop Condition
- Cropping Practices

Focus Areas

… in these regions & with these partners…

- Geographies
  - Eastern Africa*
  - US Domestic*
  - Americas
  - Asia
  - Global
- Stakeholders
  - Ag Industry
  - Markets & Trade*
  - Global Policy Frameworks
  - Food Security & Early Warning*
- NASA Integration
  - Missions
  - R & A
  - R&D Agenda
  - Across ASP

Innovation Pathways

through innovation in...

- Field Data*
- PPP*
- AI & ML
- Data Integration
- Open Platforms

Facilitating Mechanisms

with a little help from…

- Data & Tools
- Seeking Co-Funding
- Outreach & Comms
- Cap Dev Tech Transfer
- Evaluation & Impact

Harvest Focus: Public-Private Partnerships (PPP)

- PPP has emerged as a high-priority innovation mechanism for reaching Harvest’s goals. With respect to PPP, Harvest has 3 objectives:
  1. Repeatedly demonstrate successful partnerships (e.g. : Swiss Re, Planet, Applied GeoSolutions)
  2. Convene actors to facilitate collaboration
  3. Document outcomes, successful business models, & best-practices as a community good

Some highlights:

- Harvest/Planet/Farm 2050 Event (10 Dec 2019) attended by some of the biggest actors in agriculture
  - Result: interest from Corteva, Climate Corp, Bunge, AB InBev, CropX, and others to engage in an initiative to develop standard metrics for sustainability.
- *Nature Correspondence* paper on value of PPP for Ag (Coutu, Becker-Reshef, Whitcraft, and Justice)

nature

CORRESPONDENCE · 25 FEBRUARY 2020

Food security: underpin with public and private data sharing

Sylvain Coutu, Inbal Becker-Reshef, Alyssa K. Whitcraft & Chris Justice

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Next week: Soil Moisture for Agricultural Applications

April 21, 2020

Question & Answer Session

- Please enter your questions in the Q&A box.
- We will post the questions and answers to the training website following the conclusion of the course:

  https://arset.gsfc.nasa.gov/water/webinars/remote-sensing-for-agriculture-20

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- Erika Podest: erika.podest@jpl.nasa.gov