National Aeronautics and Space Administration

Food Security from Space

Monitoring Indicators of Vegetation Health on Croplands and Rangelands

Farmers and agricultural decision makers rely on many tools to assess production and allocate resources. Freely available global satellite observations provide a timely, synoptic, objective, repeatable method of surveying vegetation, supplementing traditional methods.

Legacy of Support to the Agriculture Community

NASA Earth satellites routinely monitor the amount of land cultivated; crop types grown; yield; calendars and stage (used to approximate when crops are sowed, emerge, reproduce and are harvested); gross primary production; biomass; and water status (i.e, water use efficiency, evapotranspiration). The NASA/U.S. Geological Survey Landsat satellites, operating since 1972, have created the longest space-based database of Earth satellite imagery, enabling us to follow long-term trends like deforestation and crop biomass changes. Its finer-resolution (30-meter) observations, acquired every 16 days, are complemented by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on the Terra and Aqua satellites, and the NASA/NOAA Suomi-NPP Visible Infrared Imaging Radiometer Suite (VIIRS), remotely sensing all of Earth daily at 250- to 1,000-meter resolution. The ability to fly over areas frequently is critical for timely agricultural assessments, since changes in crop status can happen in less than a week.

NASA works with operational partners to identify critical needs where satellite and airborne data can inform decision making. For example, the U.S. Department of Agriculture produces monthly estimates of global agricultural yield based on Landsat 8 and MODIS imagery that are used by the Chicago Board of Trade to set global commodity prices. Additionally, the Office of the Prime Minister of Uganda uses satellite data to trigger its Disaster Risk Financing Fund, a critical form of autonomous smallholder farm aid.

Gross Primary Production and Crop Yield

A combination of Earth observations and models support agriculture decisions. Estimates of gross primary production (GPP) — the rate biomass is produced — provide data to help determine the yields of crops and fodder for animals in rangeland systems. Satellites observe individual crops and fields, their development over the growing season and the effectiveness of management practices and interventions.

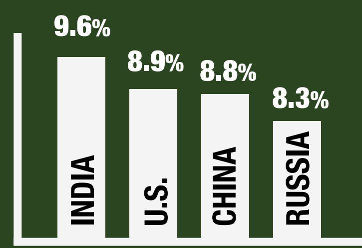
Crop-type Indicators

Thirty-meter observations from Landsat and 250-meter observations from MODIS monitor agricultural areas using the normalized difference vegetation index (NDVI), which distinguishes vegetated areas from other land surface types. These maps are used to distinguish individual crop types, and vegetated/non-vegetated areas. Measurements of NDVI over the growing season can help identify periods of crop stress and are most useful when acquired at individual fields of known crop types and calendars. Knowing stress levels when allocating photosynthate into yield provides a strong indication of crop vigor.

Landsat 8 and the European Space Agency (ESA) Sentinel-2a and Sentinel-2b provide routine land imaging and 30-meter data for crop identification, while the Harmonized Landsat and Sentinel-2 project produces 30-meter observations every 3.7 days (at the Equator). Landsat 9, planned for launch in 2020, will reduce the equatorial revisit frequency to 3 days.

About 11%
of Earth's land surface is used to grow crops.

1.87 billion hectares
(4.6 billion acres) globally[1]



Countries with the highest net cropland areas[2]

Largest U.S. crops by acreage[3]

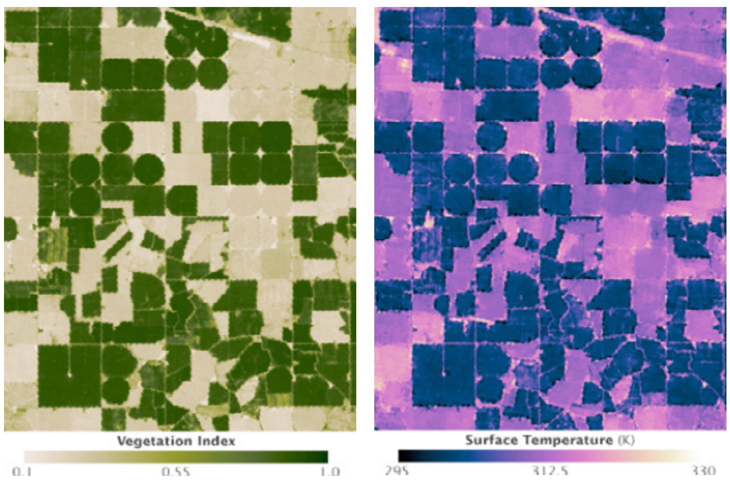
$193.5 billion
2017 market value of U.S. agricultural crops[4]

Evapotranspiration

Evapotranspiration (ET) indicates the health of vegetation and how well moisture lost on sunny days is replenished through rain or irrigation. Farmers can use satellite and airborne data on transpiration and primary production to plan irrigation, predict yields and assess the efficiency of water use (crop per drop). Longer and less cloudy days increase photosynthesis and primary production, but also increase ET, reducing available soil moisture. If moisture is not replenished, plants close their stomata to conserve water, and primary production and transpiration are measurably reduced.

Spaceborne ET estimates from current sensors rely on the visible and thermal infrared spectral ranges at spatial resolutions of 50 to 100 meters at a frequency of every two to four weeks. Landsat's thermal bands are the primary source for high-resolution field-scale ET products due to its high spatial resolution (30-meter) and sustained measurements over four decades.

IMAGES: NASA EARTH OBSERVATORY

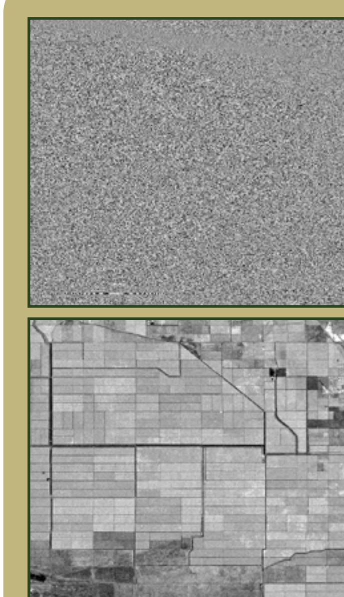


Satellite maps of vegetation (left) and surface temperature (middle) are used to calculate ET rates (right) and estimate water use. The most heavily vegetated areas are cooler because solar energy converts liquid water to water vapor instead of heating the land surface. Irrigated fields (dark blue) stand out clearly from fallow and recently harvested fields (lighter blue) and surrounding scrubland (beige).

Emerging Indicators: Solar-Induced Fluorescence and Radar Backscatter

A promising new satellite-based technique for estimating GPP has emerged in the past decade. During photosynthesis, plants absorb carbon dioxide from the atmosphere and emit a small amount of light, called solar-induced fluorescence (SIF), that can be observed at selected wavelengths of satellite spectrometers such as those on the Japan Aerospace Exploration Agency's Greenhouse Gases Observing Satellite (GOSAT), NASA's Orbiting Carbon Observatory-2 (OCO-2) satellite, and the joint Netherlands Space Office/European Space Agency TROPOspheric Monitoring Instrument (TROPOMI) instrument on the Copernicus Sentinel-5 satellite. Research shows SIF is a strong proxy for GPP, with satellite measurements of SIF closely matching ground and model-based estimates. The launch of the Orbiting Carbon Observatory-3 (OCO-3) to the International Space Station in May 2019 provides even higher-density SIF data and the ability to track SIF over the full diurnal cycle.

Another promising new technique involves applying Synthetic Aperture Radar (SAR) to agriculture. First launched on NASA's Seasat satellite in 1978, SAR instruments are active radars that transmit through clouds and receive reflections as "backscatter," that can map agricultural areas and provide information on vegetation health. This ability to see through clouds complements traditional passive optical techniques often impaired by clouds. Based on subtle changes in backscatter, SAR can detect vegetation structure and plant sprouts and can differentiate between crop types based on the timing of their growth cycles. SAR is notably applied in mapping lowland rice areas that use flood irrigation because of its ability to distinguish water from vegetation. Currently, ESA's Sentinel-1A and 1B satellites provide global SAR coverage every 12 days. The joint NASA-Indian Space Research Organization SAR (NISAR) mission, expected to launch in 2021, will provide global coverage every 12 days. Additionally, the upcoming European BIOMASS mission, expected to launch around 2021, plans to provide additional perspectives on changes in crop growth.

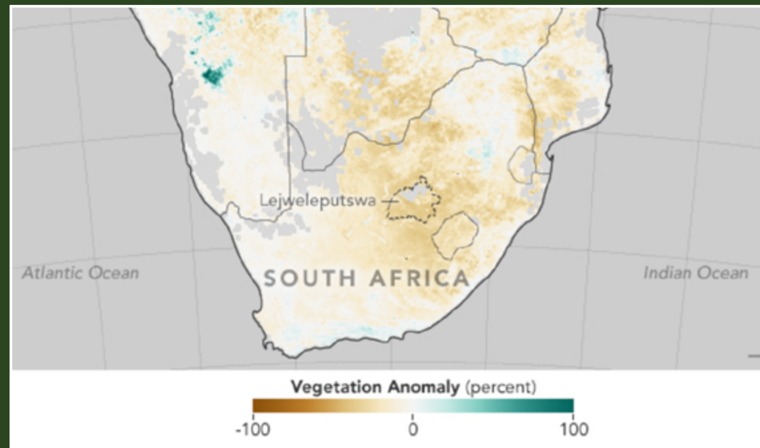


IMAGES: NASA MSFC

Backscatter received from the sensor (top) and after geometric corrections and filtering (bottom).

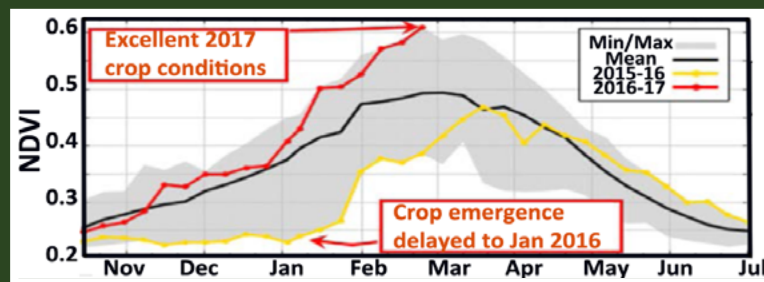
It's hard to distinguish any signal from the raw data. After geometric corrections and filtering, the image can be used for analysis.

The same field in Viljoenskroon, Free State, South Africa showing water-stressed crops on March 8, 2016 (top left) versus a bumper crop on March 1, 2017 (top middle). NDVI anomaly map of the region for December 2015 compared to the long-term average for that month from 2000–2015 (top right). Brown areas show where plant health was below normal. Greens indicate more abundant vegetation than normal for that month. Gray indicates where data were not available, usually due to cloud cover. Some areas were hit particularly hard by the drought. A graph (bottom right) of the NDVI time series for Viljoenskroon for the 2015-16 growing season (yellow line) compared to 2016-17 (red line) and to the mean (thick black line).



IMAGES: NASA EARTH OBSERVATORY

PHOTOS: USDA



GRAPHIC: USDA

Geophysical Variables Monitored

Product*	Satellite Sensors**	Spatial Resolution	Period	Frequency
Vegetation Index	Landsat MODIS Sentinel 2A&B VIIRS	30m 250m-500m 10m 750m	1984–present 2000–present 2015–present 2017–present	16 days Twice daily 5 days Daily
Leaf Area Index	MODIS	500m	2000–present	Multi-day
Crop Water Demand (Evapotranspiration)	Landsat	100m	1984–present	Weekly
Surface Temperature	Landsat MODIS VIIRS	100m 1km 325m	2000–present 2000–present 2017–present	16 days Twice daily Daily

* *Products available at* science.gsfc.nasa.gov/610/applied-sciences/food.html

** *Satellites operated by NASA and other U.S. and international agencies*

Data Sources and Training

The information presented here focuses on NASA resources and datasets distributed through the Goddard Earth Science Data and Information Services Center.

Webinar: Vegetation Index: arset.gsfc.nasa.gov/land/webinars/advancedNDVI

References

[1]Food and Agriculture Organization: data.worldbank.org/indicator/AG.LND.ARBL.ZS

[2]USGS: www.usgs.gov/news/new-map-worldwide-croplands-supports-food-and-water-security

[3,4]USDA 2017 Census of Agriculture: www.nass.usda.gov/Publications/AgCensus/2017/

[5]U.S. Department of Agriculture, February 2019. World Agricultural Production, Washington, D.C., USA. 32 p.

[6]Whitcraft, A.K., Becker-Reshef, I., Justice, C.O., 2015. A framework for defining spatially explicit Earth Observation requirements for a global agricultural monitoring initiative (GEOGLAM). Remote Sensing 7, 1461–1481.

NASA Food Security Program

We live in a hungry world. A rapidly growing world population, its socioeconomic development, and finite natural resources in the midst of more frequent extreme weather and a changing climate, all increase our vulnerability to any disruption in the food system. Maintaining situational awareness about food production requires the global view of Earth as a system that only a fleet of satellites can provide.

IMAGE: NASA EARTH OBSERVATORY

Agribusiness in the Colorado River floodplain where the Mohave nation meets Arizona, Nevada, and California: commodity crops alfalfa, corn, and soybeans are grown in rectangular and round fields.

To help address these urgent challenges, NASA partners with operational agencies such as the U.S. Department of Agriculture (USDA), the U.S. Agency for International Development (USAID) and the National Oceanic and Atmospheric Administration (NOAA), along with international organizations and private industry, and sponsors Harvest, a Food Security and Agriculture Consortium led by the University of Maryland to advance the use of remotely-sensed data for more informed decision-making.

The Harvest Consortium is a NASA-funded collection of partners with domestic and international activities that are enhancing the use of satellite data in agricultural decision-making. Harvest places a strong emphasis on transitioning research to operations.

We also have a team of NASA scientists with expertise in food and water systems, working with universities, governmental and non-governmental organizations to support the food security and agriculture communities in a more agile and futuristic way.

These researchers draw on the ingenuity of NASA with its unique technological and scientific capabilities in synergy with the NASA Harvest Consortium.

The NASA Food Security Program also:

- Fosters the assimilation of satellite and airborne remote sensing data into Earth systems models and other tools designed to address global food security challenges.
- Explores the research needs, sources of uncertainty and technical barriers that limit the operational use of Earth observations in decisions.
- Works with NASA's Earth Science Technology Office to advance state-of-the-art technology to public and private agencies focused on global food security challenges.
- Works with current and future NASA missions before and during their formulation to ensure that food security science and applications are incorporated into new satellite missions.
- Represents NASA on government initiatives, assisting interagency programs in the use of NASA resources.

PHOTO: SIMON SKAFAR/ISTOCK

A new generation of farmers uses aerial and satellite remote sensing imagery to help efficiently manage croplands. Farmers monitor a range of variables that affect their crops—such as soil moisture, surface temperature, photosynthetic activity, and more.

Further Reading

NASA Food Security Program: science.gsfc.nasa.gov/610/applied-sciences/food.html

NASA Harvest: nasaharvest.org

NASA · USAID · USDA · NOAA · University of Maryland 1856 · HARVEST EARTH DATA

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