Multi-Sensor Monitoring of Ecosystem Dynamics: Overview and Update

Garik Gutman, NASA HQ

Washington, DC USA

Capacity Building in Eastern Europe
NASA-ESA Trans-Atlantic Training Initiative (TAT)

- Origin: after the training session for the LCLUC ST meeting, Latvia, 2010
- Concept: while visiting Charles University in Prague, 2012
- NASA-ESA agreement
- Implementation: Prague, 2013
- Under careful supervision by a NASA Program Manager

TAT-1	2013, Prague, Czech Rep.
TAT-2	2014, Krakow, Poland
TAT-3	2015, Brašov, Romania
TAT-4	2016, Zvolen, Slovakia
TAT-5	2017, Pecs, Hungary
TAT-6	2018, Zagreb, Croatia
TAT-7	2019, Novi Sad, Serbia

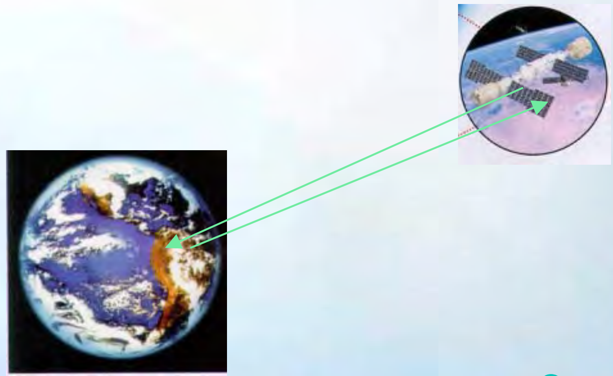
TAT-2020 postponed

TAT-8 2021, the first **joint** European virtual TAT session, organized by Aristotle U., associated with the SCERIN+MedRIN joint virtual workshop to be held Jun 15-17

Remote Sensing: Passive and Active

- Passive Systems
  - Use natural energy sources: Sun
  - Reflected/emitted energy
- Active Systems (Radars, Lidars)
  - Have their own energy source
    - Work in the dark
  - Radar – all-weather sensor
  - Lidar – optical, clear conditions

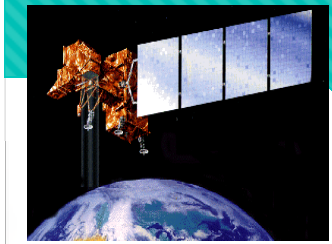
Passive, Reflected

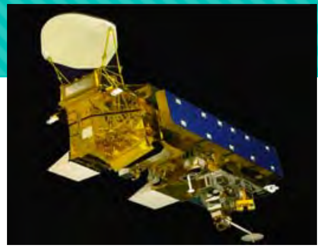


Active (Radar, Lidar)

NASA Missions for Land Remote Sensing

Systematic Missions - Observation of Key Earth System Interactions





Landsat 9
Sep 2021

Landsat 7
4/15/99

Terra
12/18/99

Aqua
5/3/02

ASTER MODIS

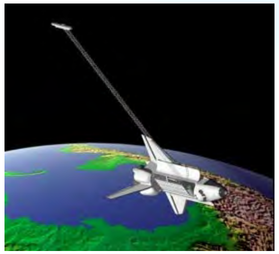
Suomi-NPP
10/28/11

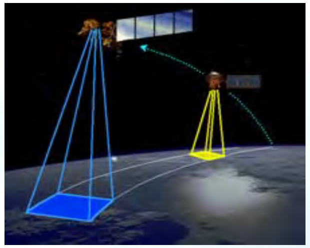
VIIRS

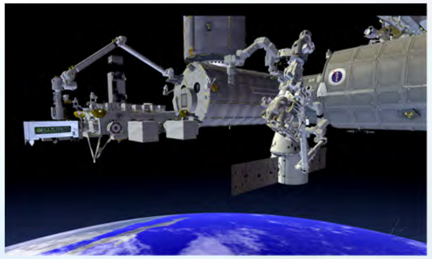
Landsat 8
2/11/13

Exploratory Missions –
Exploration of Specific Earth System Processes
and Demonstration of Technologies

International Space Station
(ISS)







ShuttleRadar Topography Mission SRTM active
2/11/02-2/22/02
Space Shuttle Endeavour

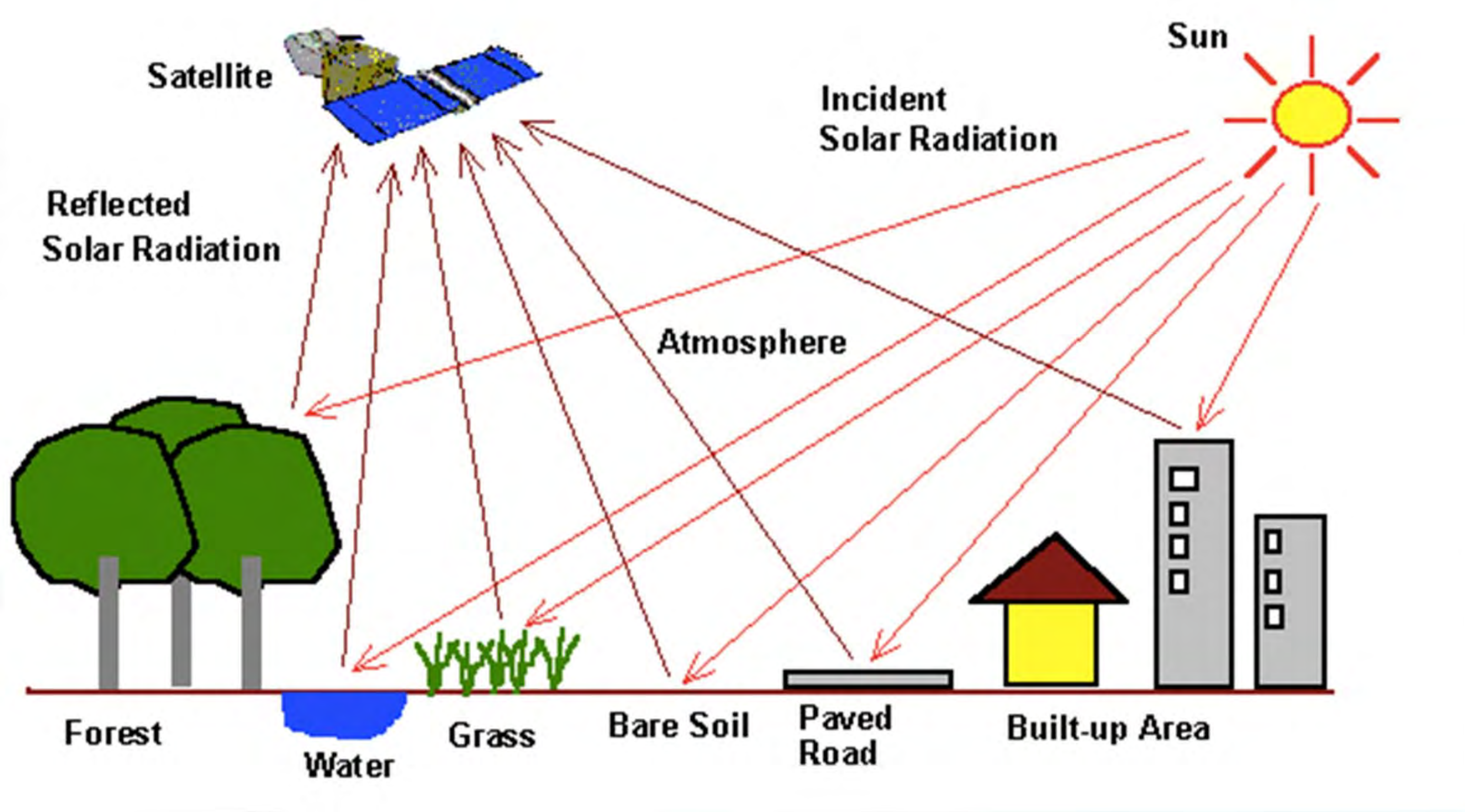
Earth Observing EO-1

ALI (predecessor of Landsat-8)
Hyperion – first hyperspectral in space

11/21/00-3/30/2017

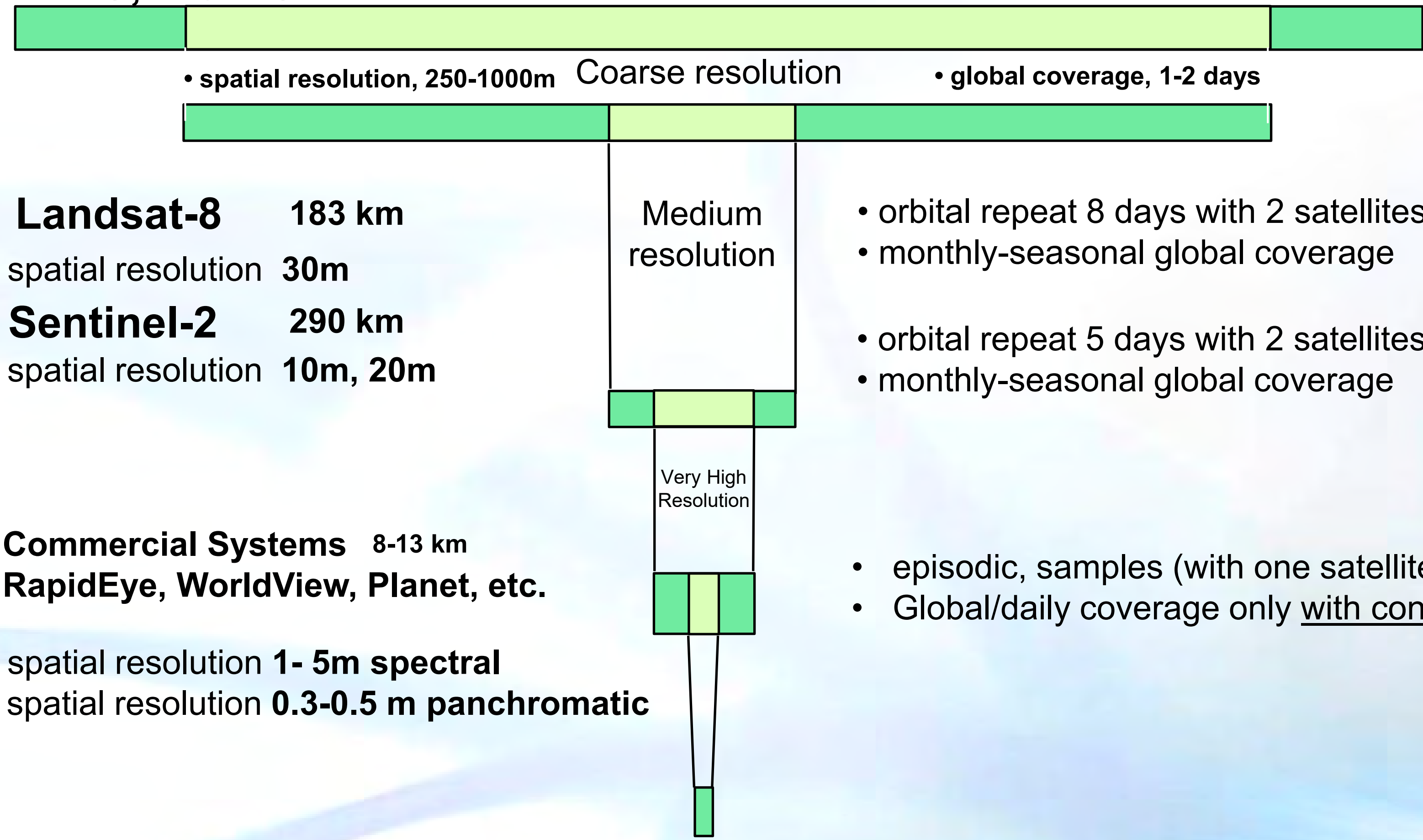
ECOSTRESS (thermal IR)
GEDI (Lidar) active
DESIS (Hyperspectral)
All launched in 2018

Passive Optical Remote Sensing



Synergistic Use of Optical Remote Sensing

VIIRS, MODIS — **2300-3000 km swath**



- **spatial resolution, 250-1000m**
- **global coverage, 1-2 days**

Landsat-8 **183 km**

- spatial resolution **30m**
- orbital repeat 8 days with 2 satellites
- monthly-seasonal global coverage

Sentinel-2 **290 km**

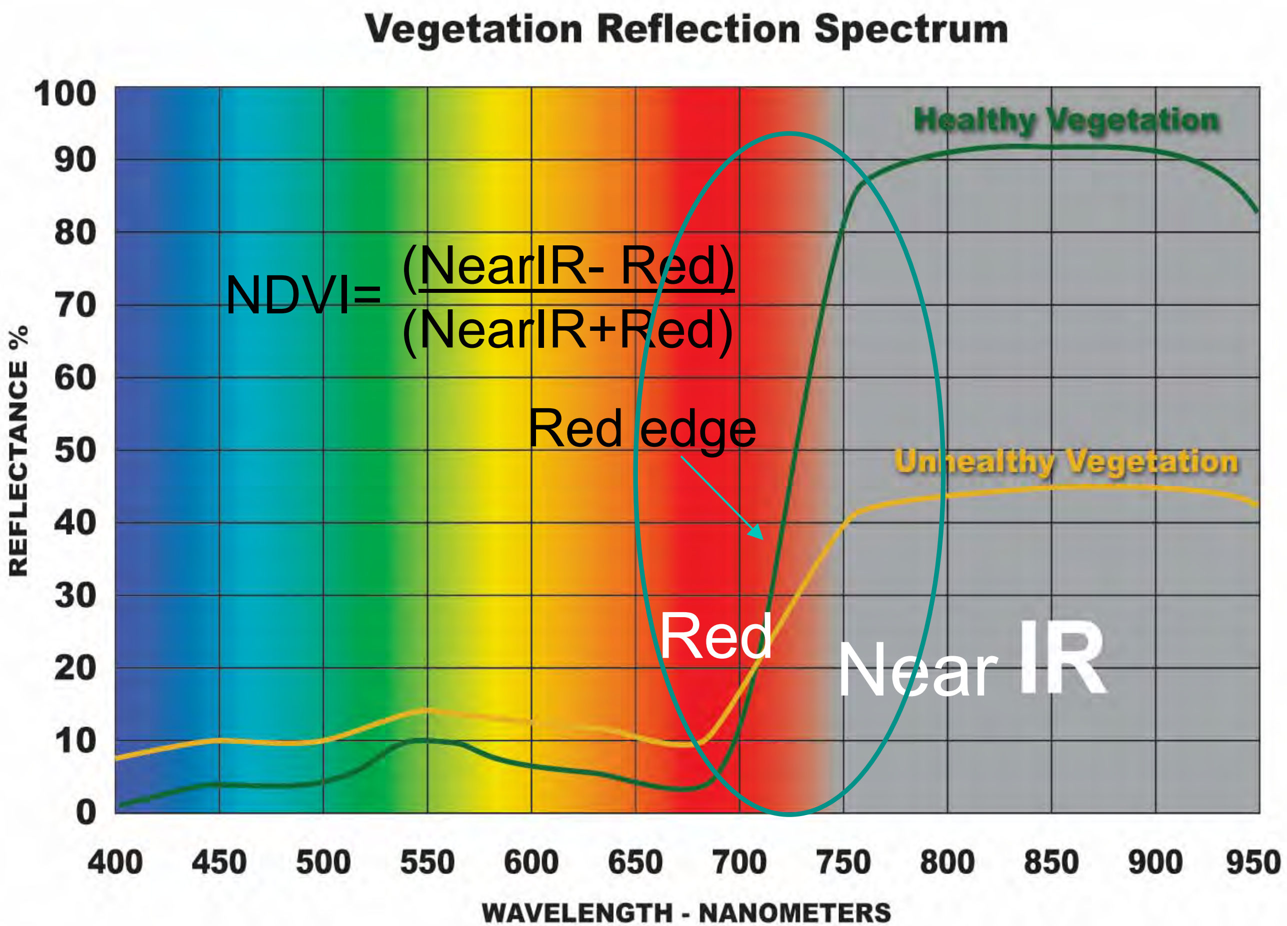
- spatial resolution **10m, 20m**
- orbital repeat 5 days with 2 satellites
- monthly-seasonal global coverage

Commercial Systems **8-13 km**
RapidEye, WorldView, Planet, etc.

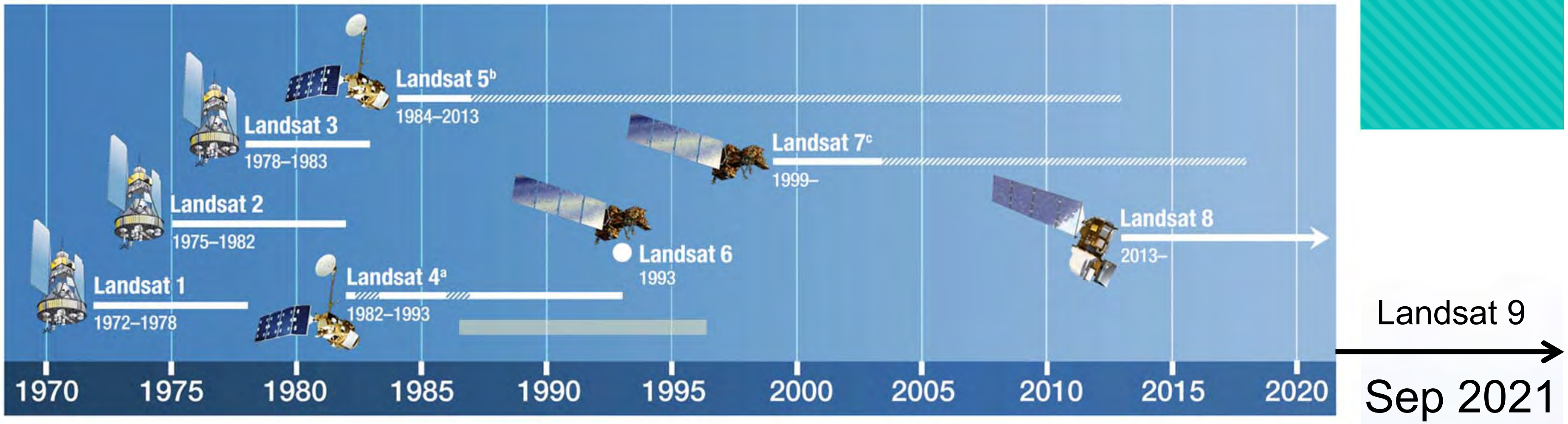
- spatial resolution **1- 5m spectral**
- spatial resolution **0.3-0.5 m panchromatic**

- episodic, samples (with one satellite)
- Global/daily coverage only <u>with constellations</u>

Principle for Remote Sensing of Vegetation



Landsat



[a]Limited data due to transmitter failure soon after launch. Only 45,172 Landsat 4 Thematic Mapper scenes from 1982–1993 available for science users—~10 scenes/day (vs 725 scenes/day from L8)

[b]Data coverage limited to Continental US (CONUS) and International Ground Station sites after a transmitter failure in 1987; Multispectral Scanner turned off in August 1995

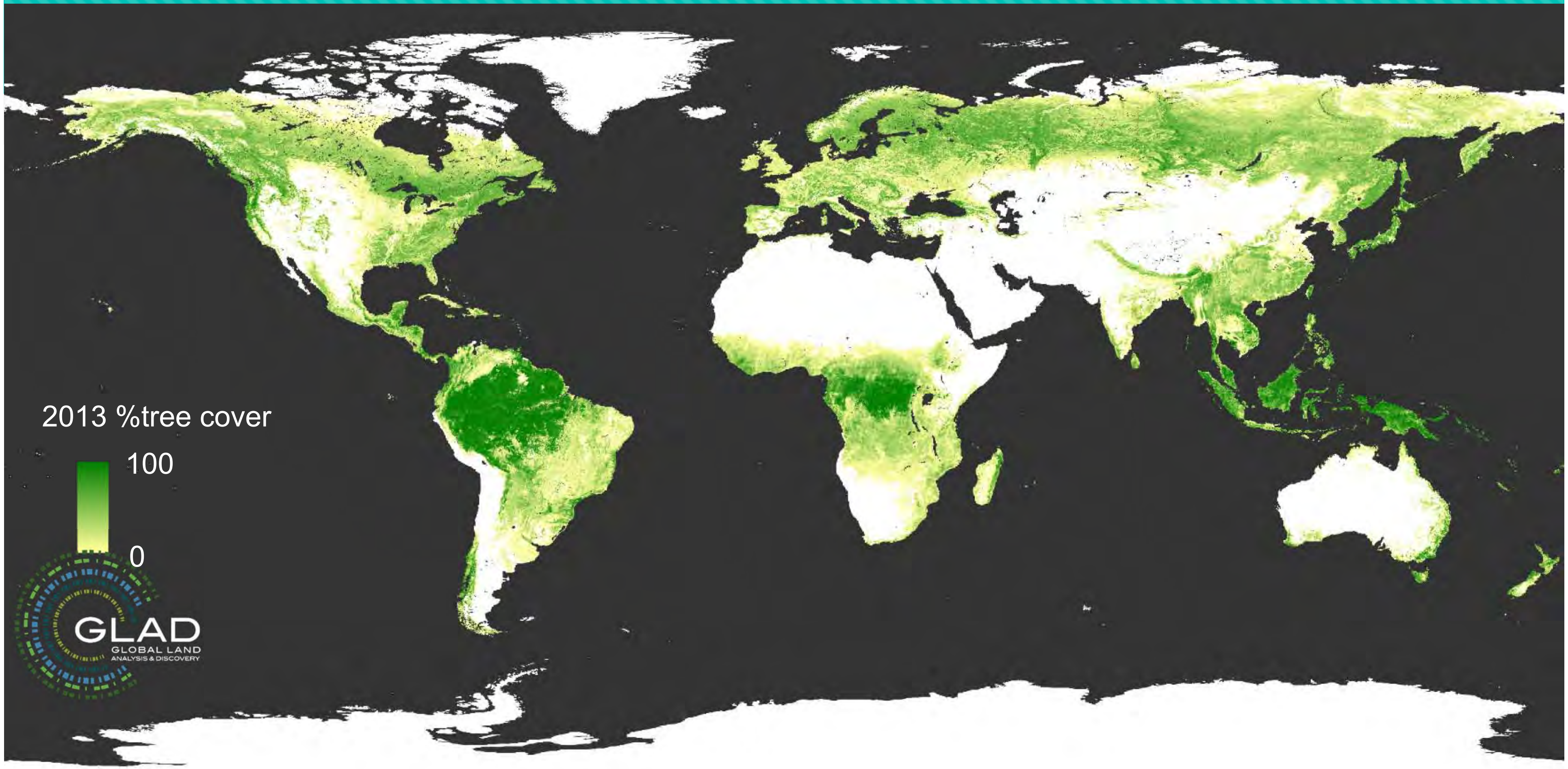
[c]Degraded Performance due to Scan Line Corrector failure in May 2003

- The Landsat program: Earth Resources Technology Satellites Program 1966, Landsat 1 (ERTS) launched in July 1972
- Thermal band added for Landsat 3 and beyond
- After launch, Landsat operations are transferred to USGS, то collect, archive, process,and distribute the image data
- Until 2010 expensive, free now!
- Two-Landsat system frequency revisit time: 8 days
- May not provide enough observations for monitoring rapid changes (e.g., Ag)
- Sufficient for monitoring slow changes (e.g., Urbanization, Deforestation)

Landsat Products and Applications

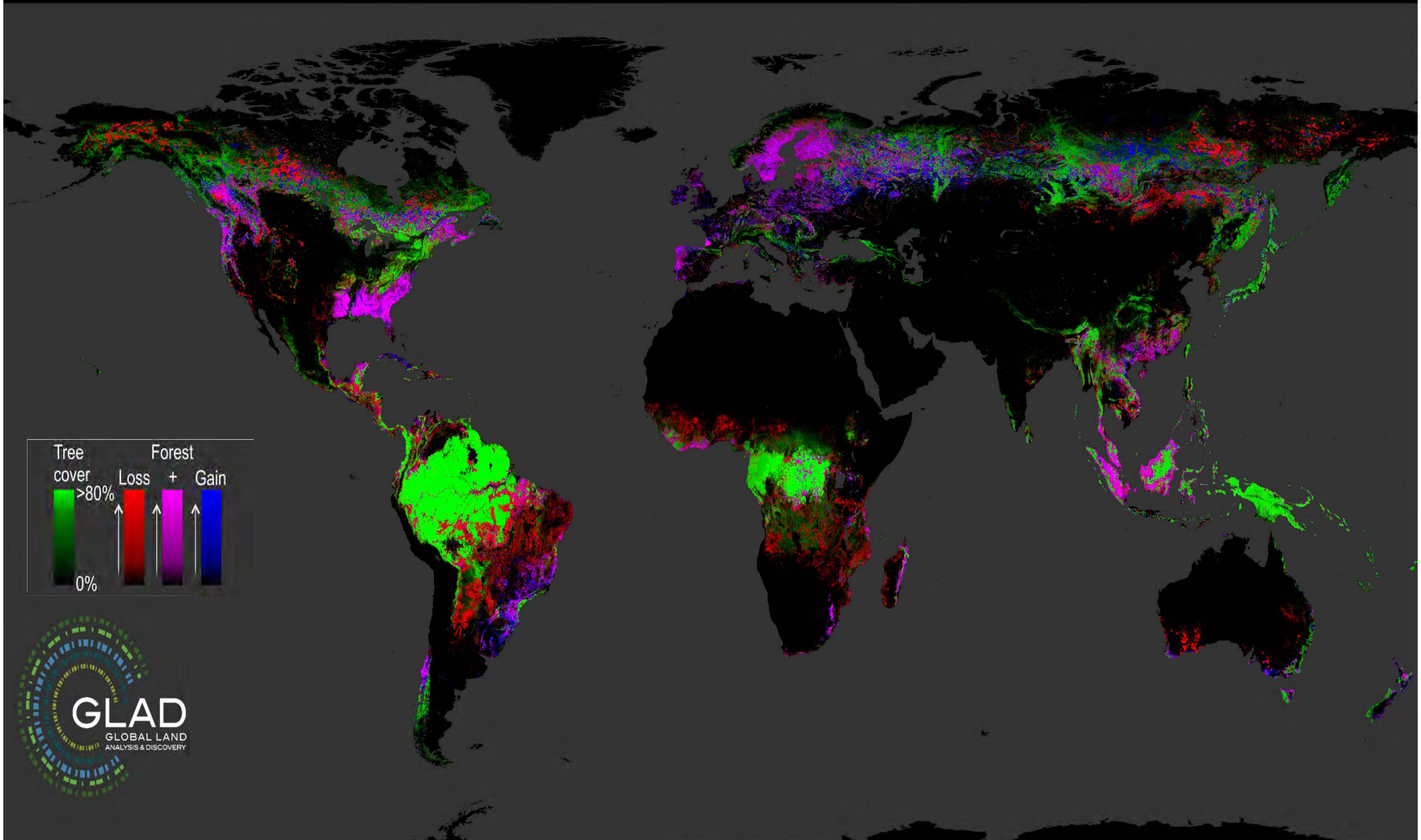
- Global Products
  - Global Tree Cover
  - Forest Cover Change
  - Forest Height
  - Global Croplands
  - Global Impervious Surface
- Applications
  - Agriculture
  - Forestry
  - Range Resources
  - Urbanization
  - Geology
  - Hydrology
  - Coastal Resources
  - Environmental Monitoring

Global Distribution of Tree Cover from Landsat: 2013



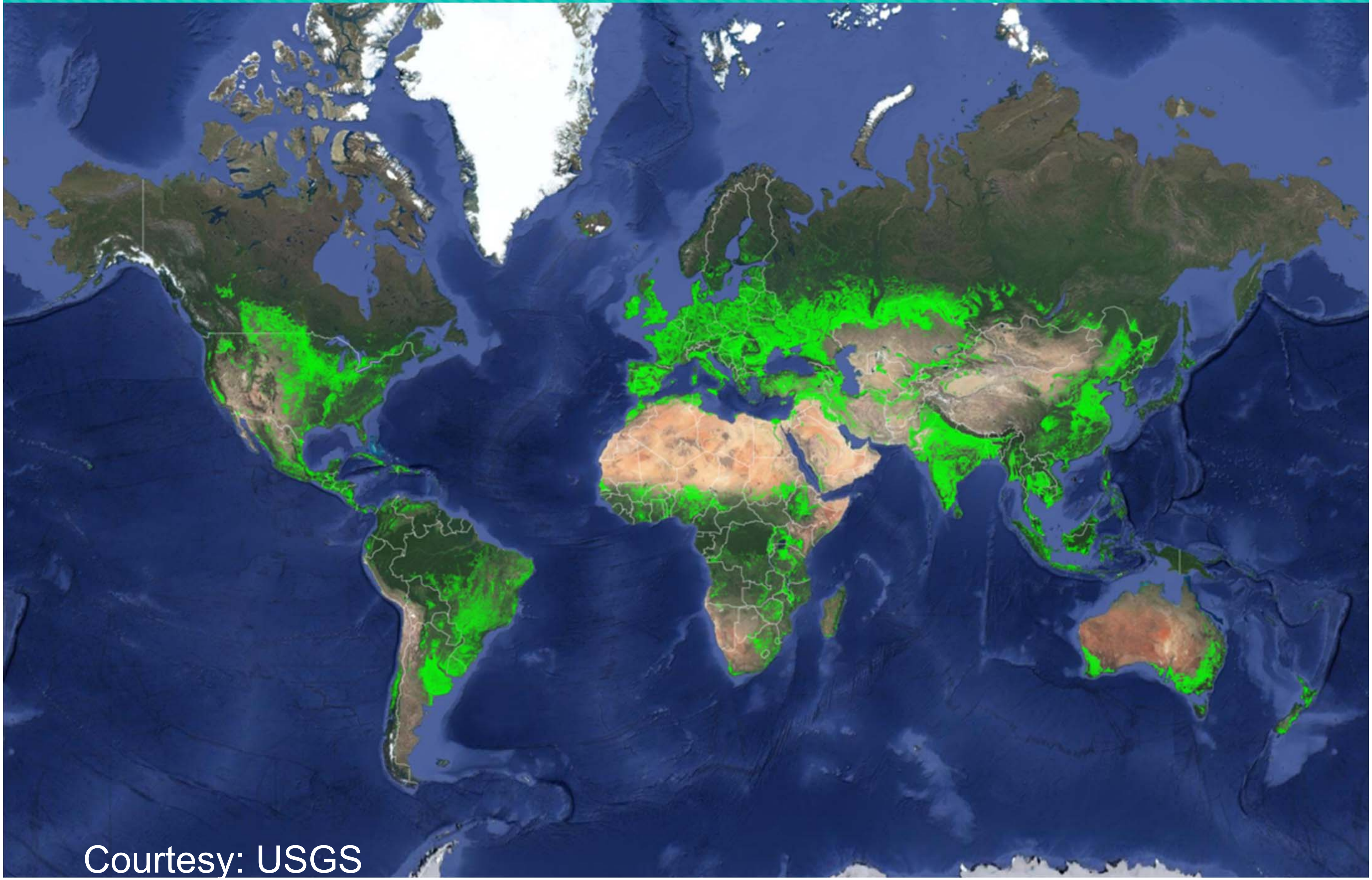
Courtesy: Hansen et al. (U. Maryland)

Tree Cover Extent and Forest Loss and Gain from Landsat: 2000-2014



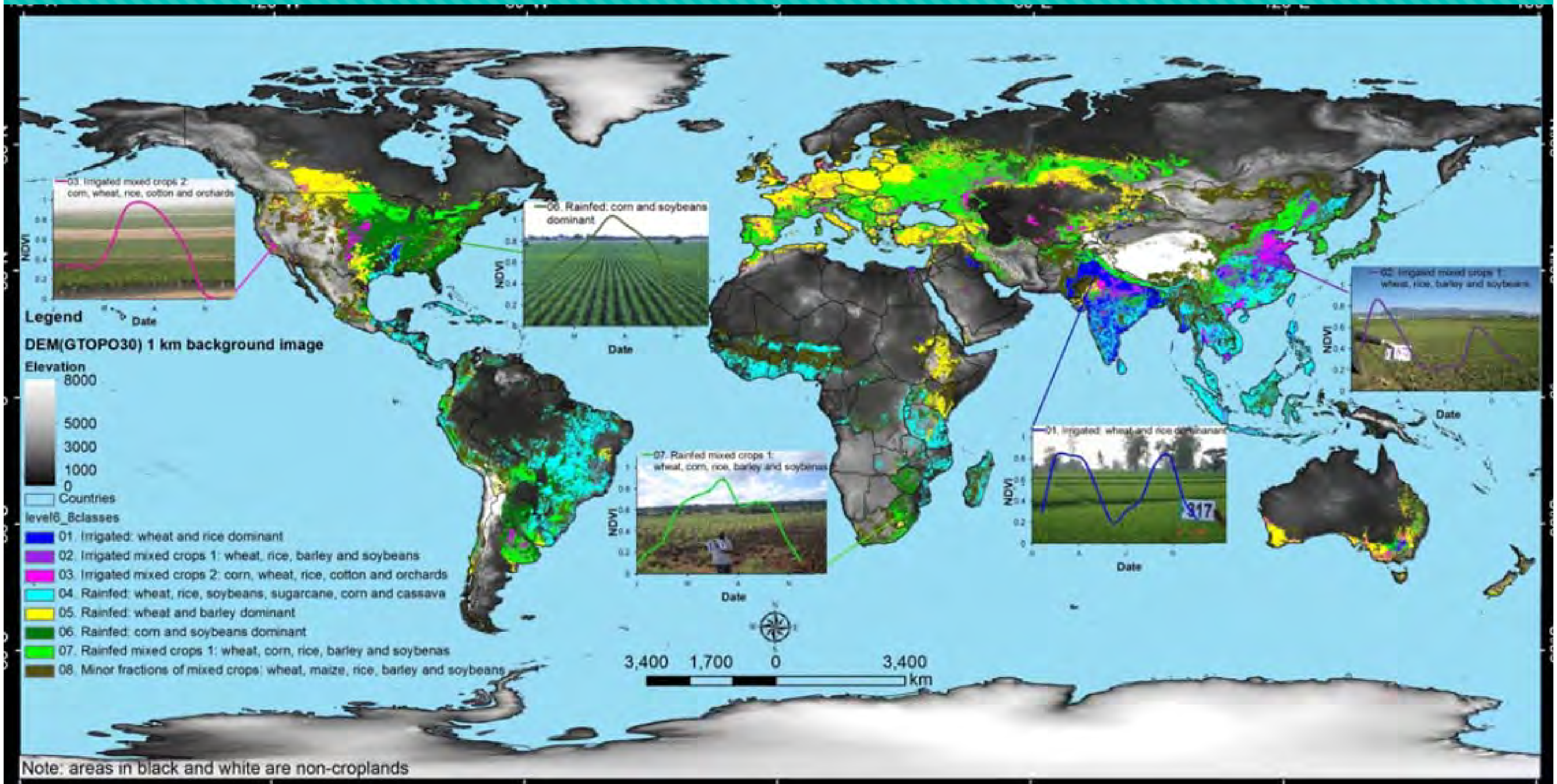
Courtesy: Matt Hansen et al., U. Maryland

Global Croplands



Courtesy: USGS

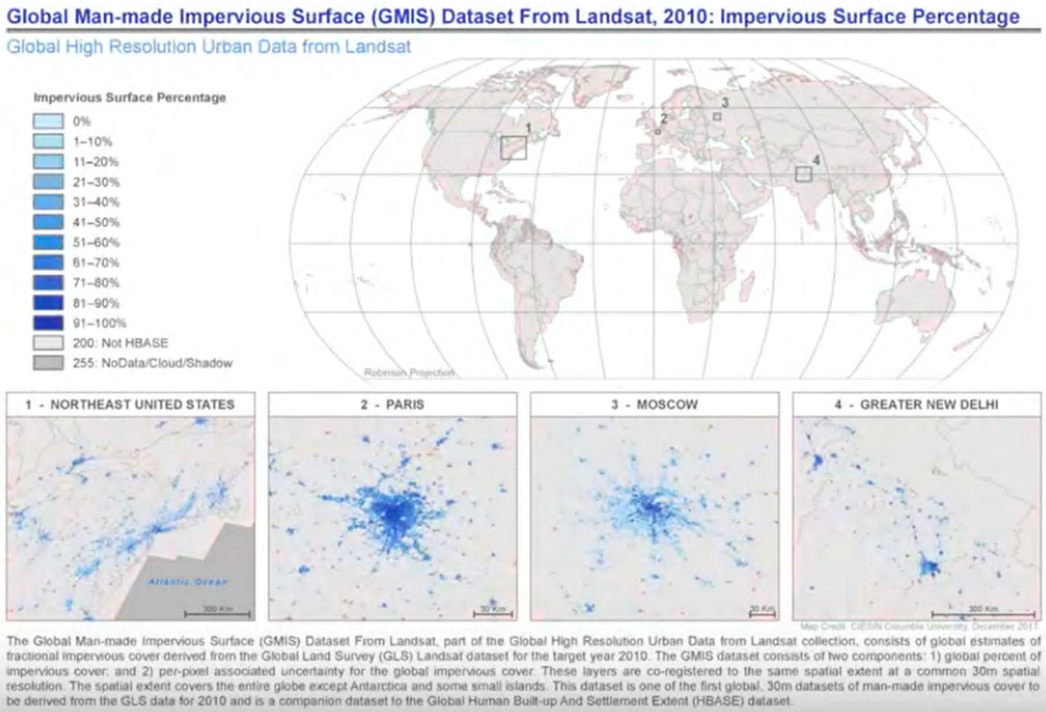
Global Croplands: Irrigated and Rainfed

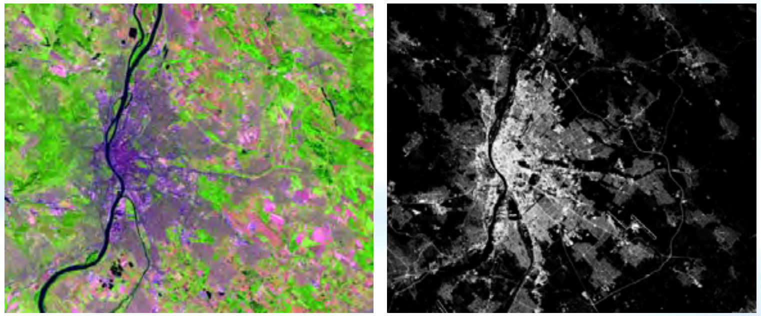


Courtesy: Prasad Thenkabail, USGS

Global Impervious Surfaces

"The Global High Resolution Urban Data from Landsat data collection contains the two companion data sets produced by **NASA Goddard Space Flight Center (Eric Brown de Colstoun) and University of Maryland (Cheng Huang)**"

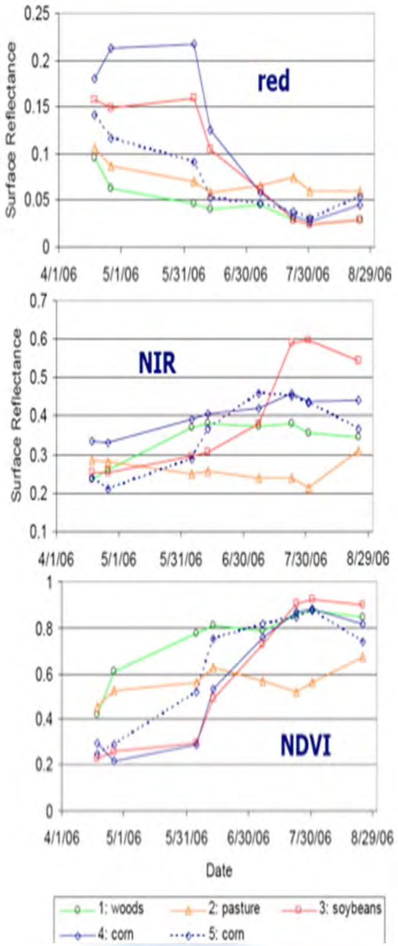




Budapest from Landsat (2010)

- LCLUC Global Products
  - Global Man-made Impervious Surfaces
  - Global Human Built-up And Settlement Extent

Prior to ESA Sentinel Program: Merging Data From Landsat-like Mid-Resolution Sensors



Land-cover phenology at 30 m

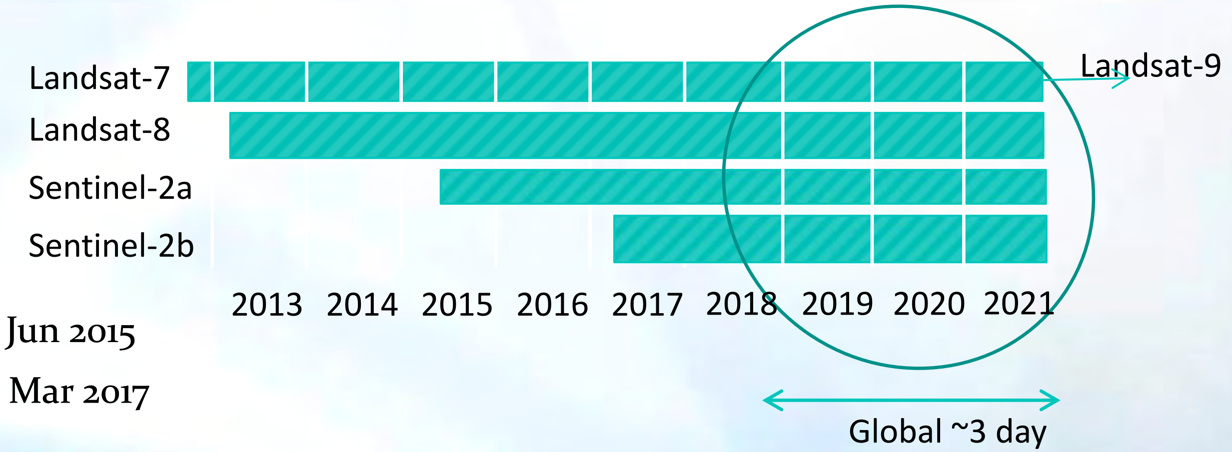
- Red reflectance, near-infrared (NIR) reflectance, and NDVI=(NIR-Red)/(NIR+Red) values for individual fields from central Illinois during the first half of the 2006 growing season

- Data are combined from **Landsat-5, -7, ASTER, and IRS**

Courtesy: Feng Gao, USDA

Sentinels to the Rescue!
Multi-Source Land Imaging

Merging Sentinel-2 + Landsat data streams could provide < 5-day coverage for Ag monitoring
- Both sensors have 10-30m coverage in VNIR-SWIR
- Satellite orbits complementary

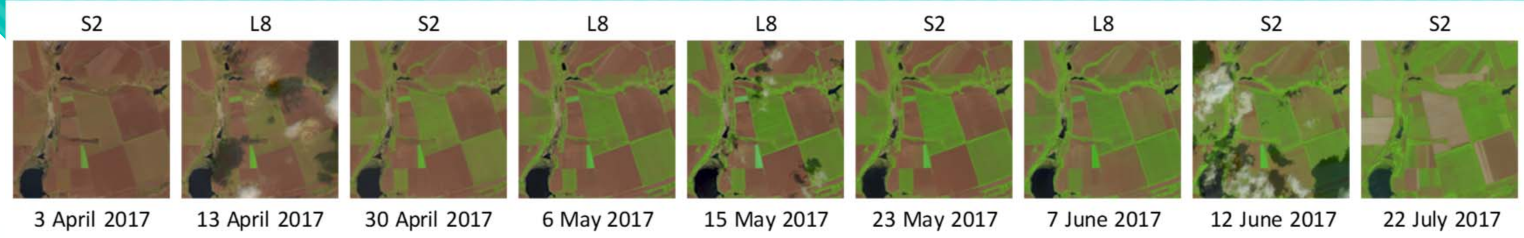


- Sentinel-2a: launched in Jun 2015
- Sentinel-2b: launched in Mar 2017

- Landsat-7: launched in Apr 1999
- Landsat-8: launched in Feb 2013
- Landsat-9: planned for Sep 2021

Crop Yield Assessment and Mapping from Landsat-8 and Sentinel-2 observations

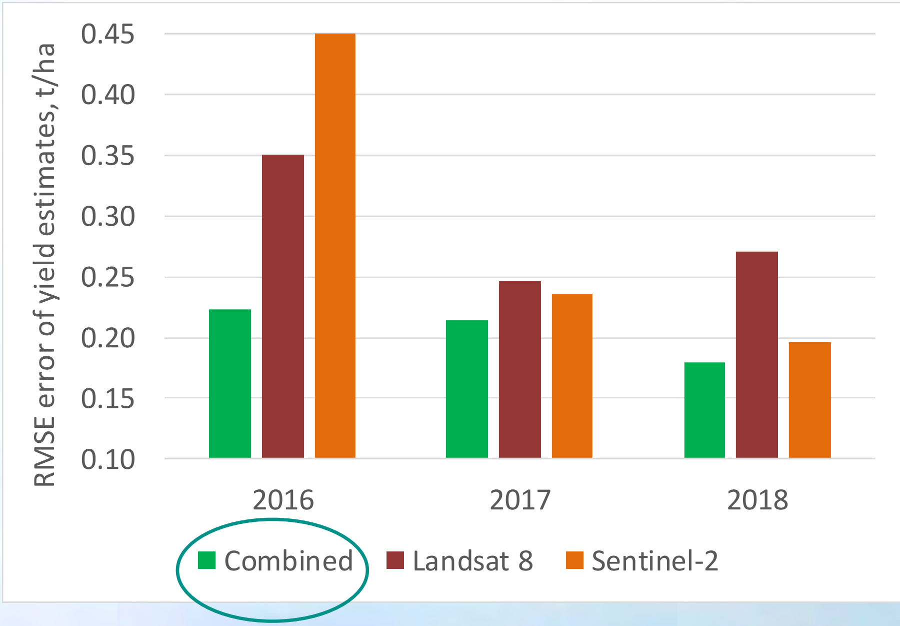
PI: Skakun, U. Maryland



Ukraine
(Kirovograd obl.)

Root mean square error (RMSE) of the relationship between *crop yield* (ground data) and *cumulative satellite-derived vegetation index*

Multi-source (L8+S2) reduction in *RMSE* →

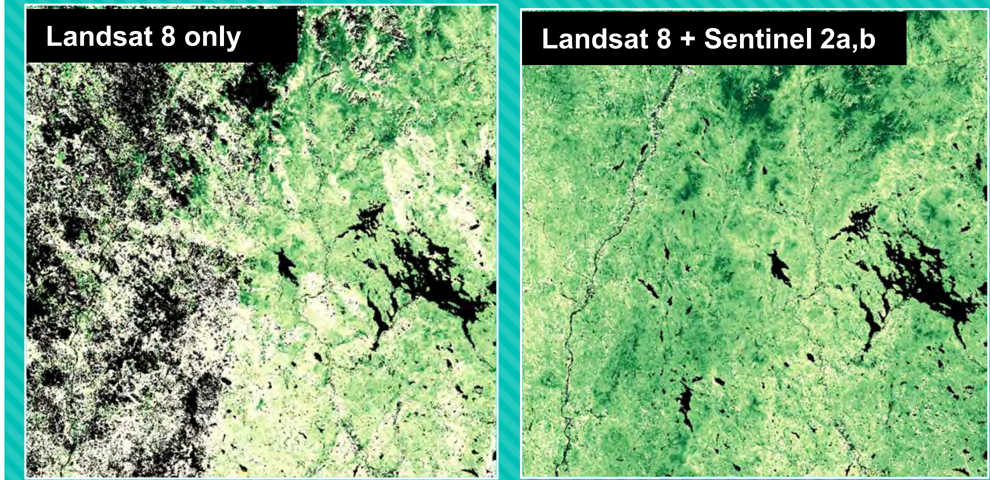


2016, 2017 – Sentinel 2a
2018 – Sentinel 2a,b

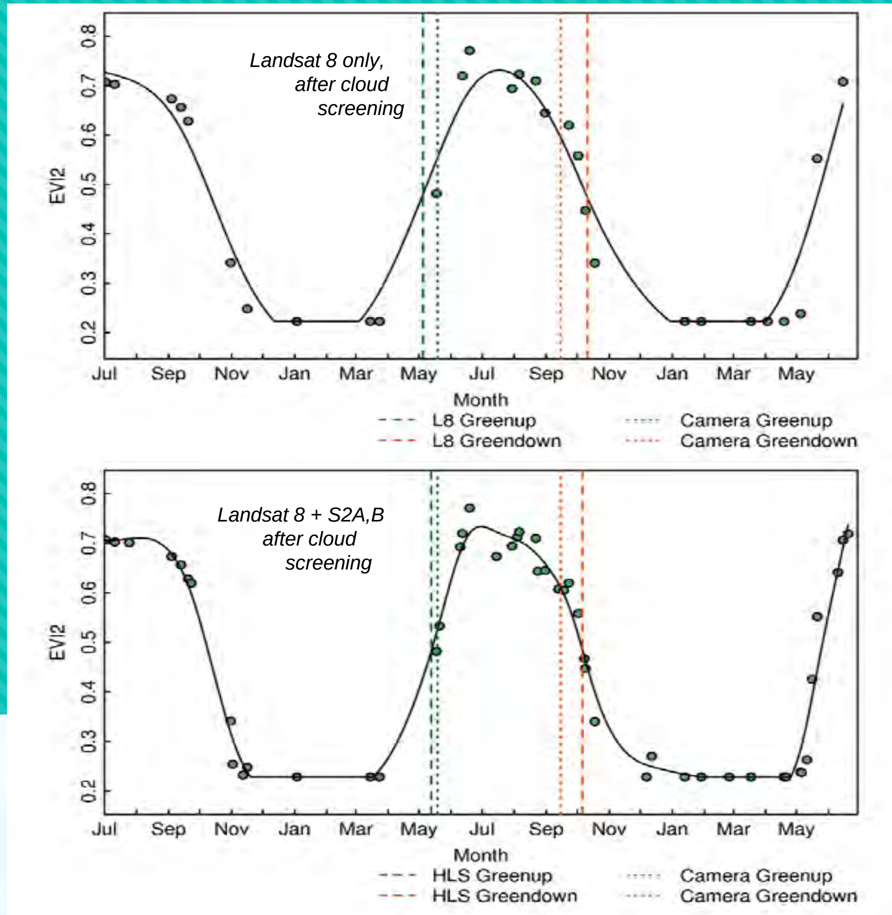
Satellite-Derived Greenup for Broadleaf Forests

PI: Friedl, Boston U.

New Hampshire



-- No prediction due to insufficient data density



Regression against PhenoCam greenup obs

	Landsat	Sentinel	L8+S2
RMSE	12.6	17.0	8.4
R^2	0.62	0.32	0.81

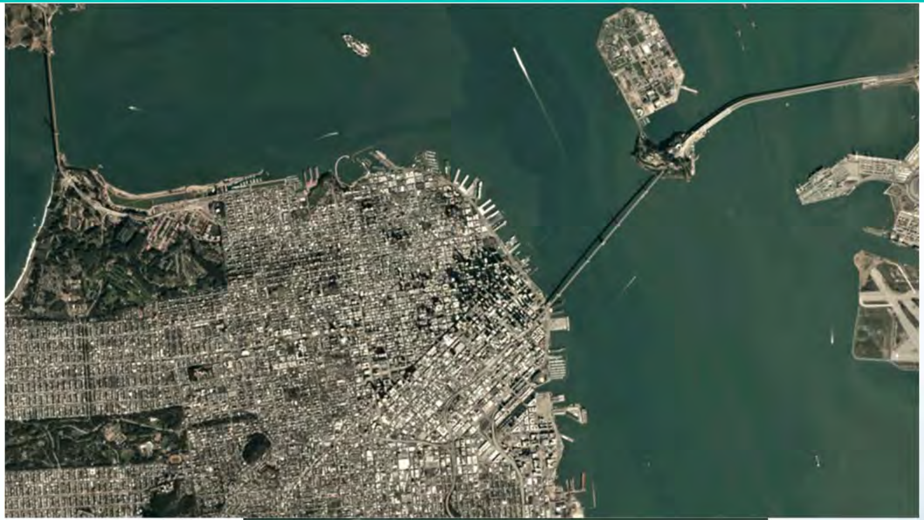
Increased temporal density results in more complete and more accurate retrieval of phenology

Courtesy: Doug Bolton, BU

Zooming-in: Very High Resolution (VHR)

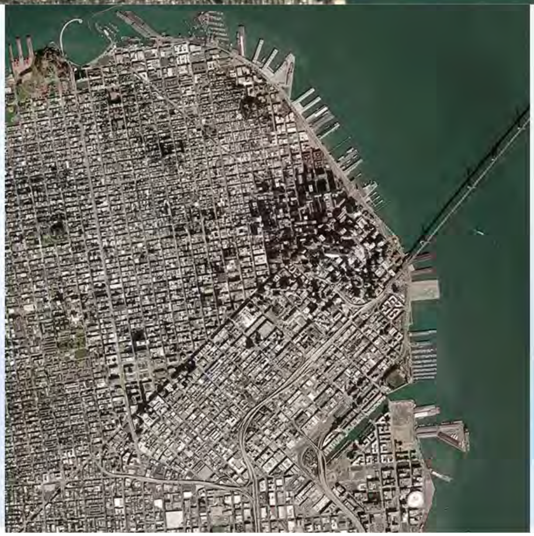
Commercial satellites offer images at fine spatial scale and high temporal resolution

San Francisco



Planet Labs constellation acquire daily images of the Earth with a 3-m spatial resolution

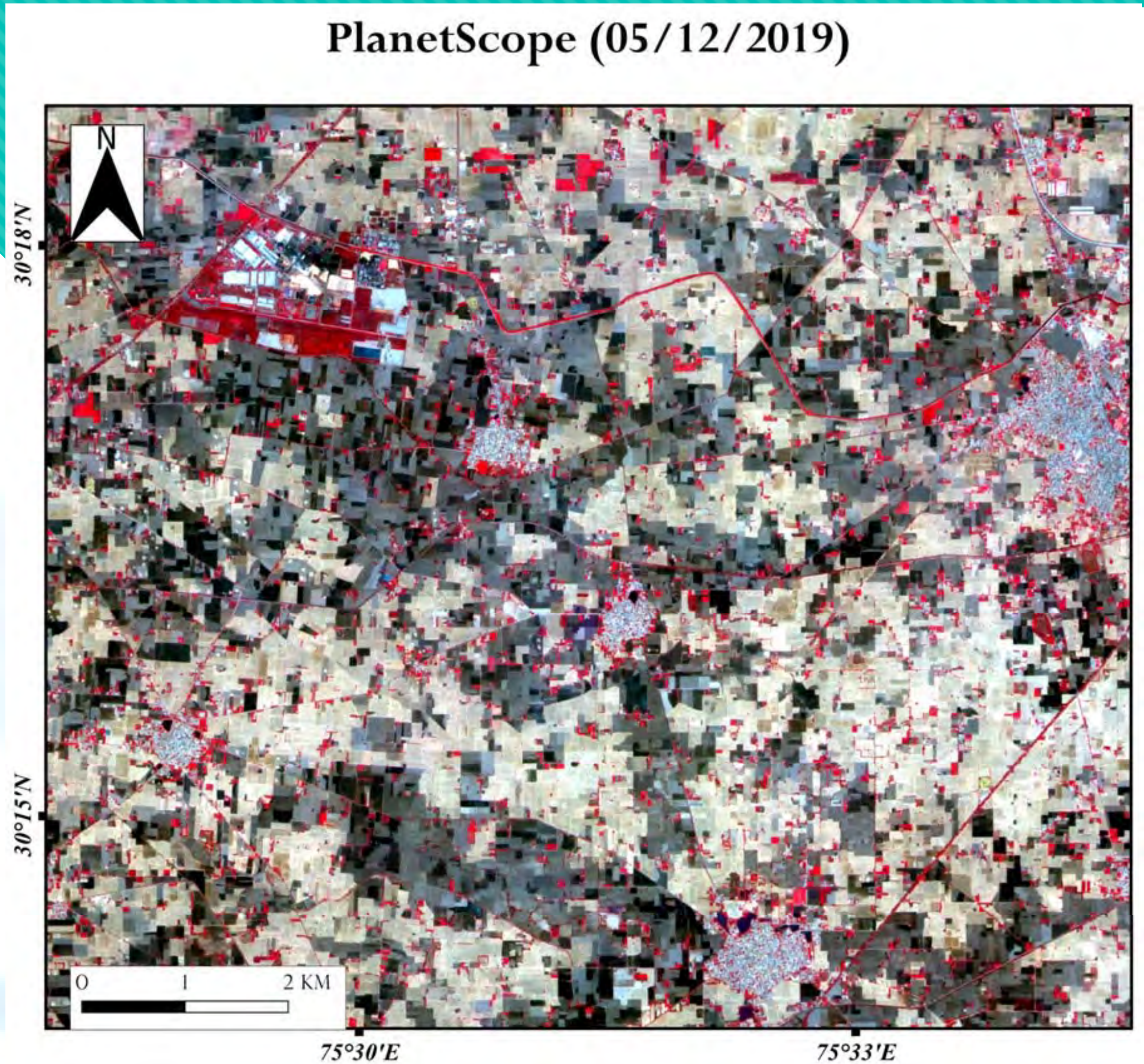
https://www.planet.com/pulse/mission-1/



Maxar (Digital Globe, WorldView)
- Spectral bands ~1m
- Panchromatic band 0.3m

https://blog.maxar.com/earth-intelligence/2021/introducing-maxar-ard-accelerating-the-pixel-to-answer-workflow-with-analysis-ready-data

From Landsat 30m to Planet 3m



PLANETSCOPE (3m) vs LANDSAT (30m): clearer distinction of agricultural field borders and burnt areas in India

Plantations

Wheat

Burnt areas

Fallow

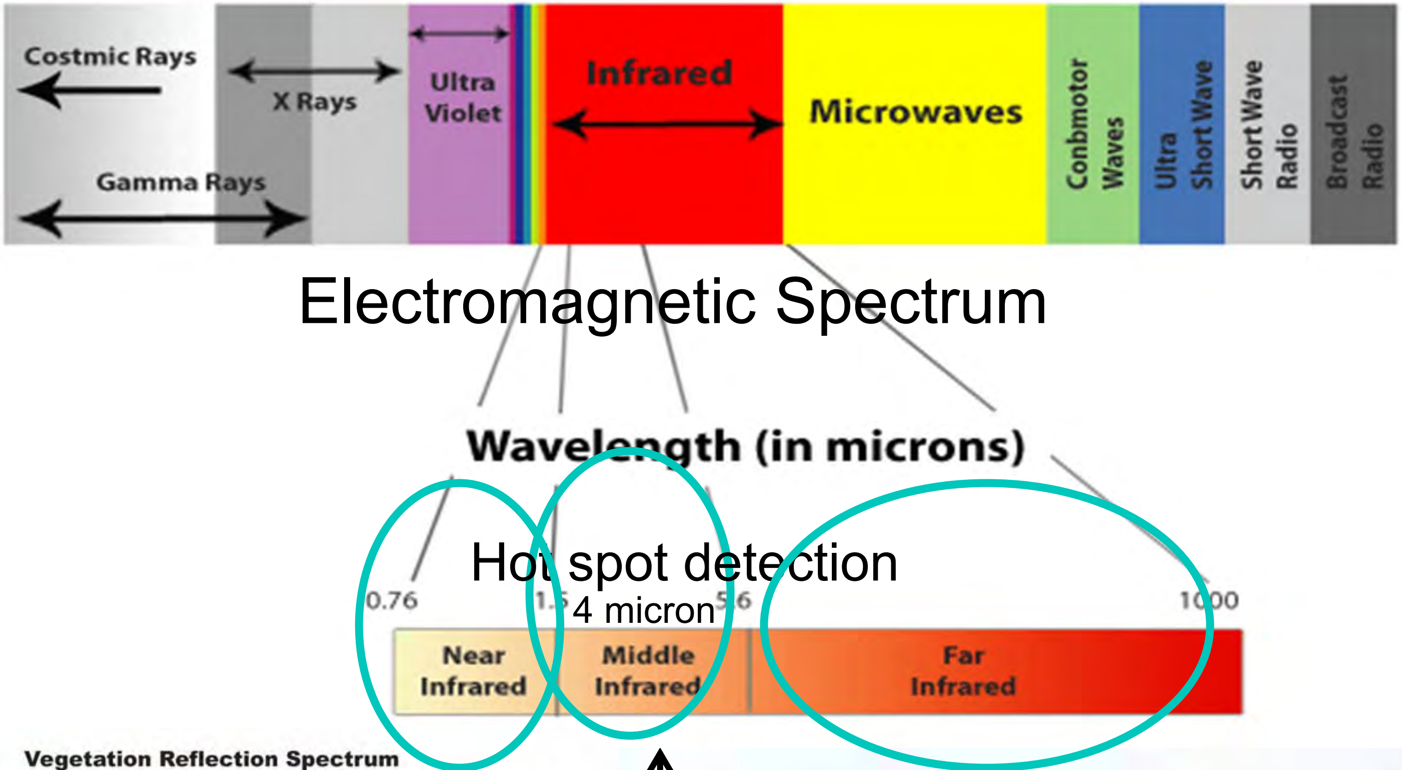
RGB=NIR, Red,

Courtesy: Krishna Vadrevu, NASA

Prospects for Using VHR Imagery

- Limited Planet datasets are available for free already now at Universities
- Wall-to-wall VHR data over tropics purchased by the government of Norway (to tackle tropical deforestation)
  - https://earthobservations.org/geo_blog_obs.php?id=498
- NASA purchases VHR data for NASA-affiliated projects
- Special LCLUC issue on the use of VHR data
  - https://www.mdpi.com/journal/remotesensing/special_issues/LULC_VHR

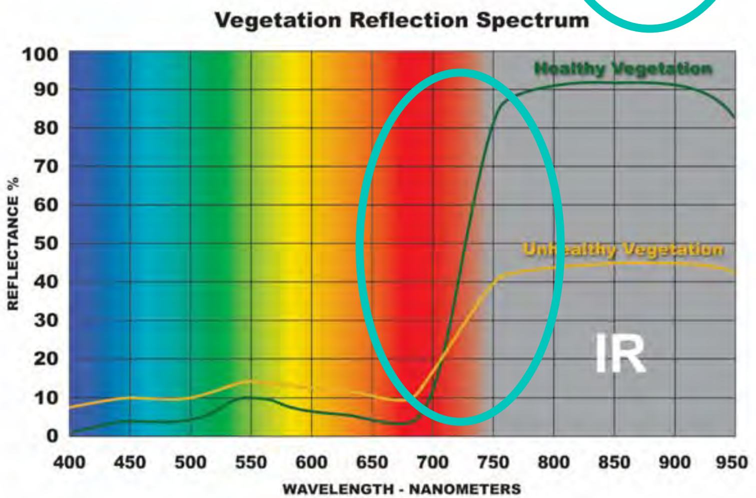
Infrared Remote Sensing



Electromagnetic Spectrum

Hot spot detection

4 micron

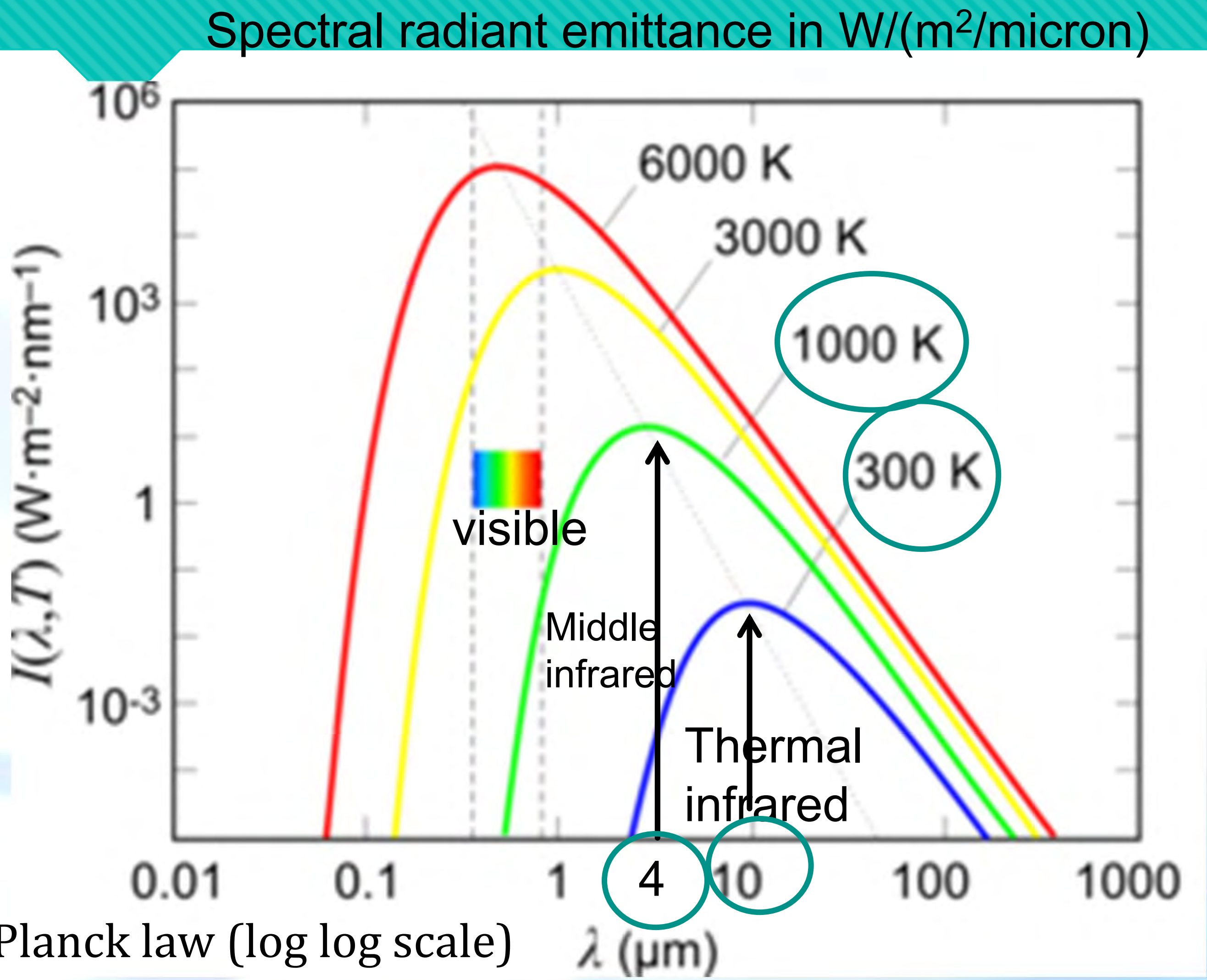


Land Surface temperature
11 micron

Fire 4 micron

http://www.eumetrain.org/data/3/30/print_5.htm

Infrared Remote Sensing



Planck law (log log scale)

Istanbul from TERRA/ASTER: June 2000

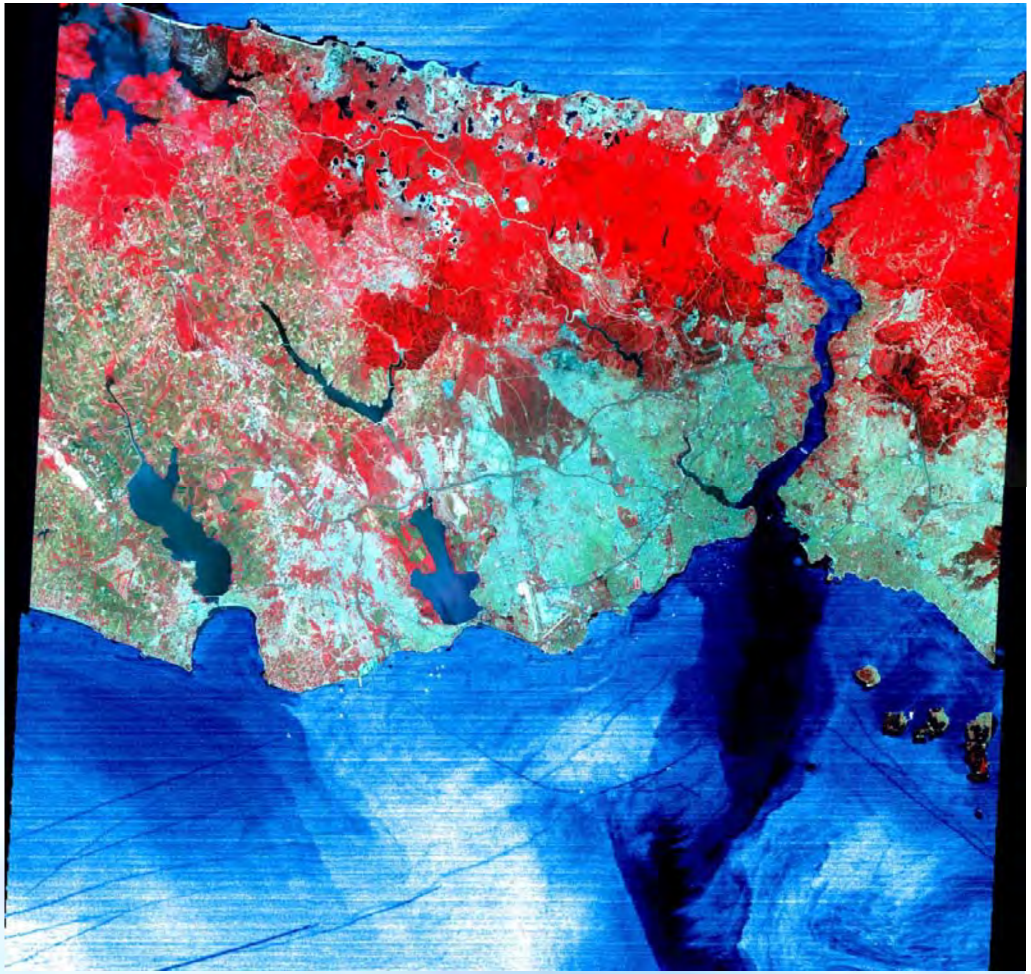
visible (15m) + infrared (90m) channel combination

Vegetation: red
Urban: blue-green

Cold waters: dark blue
Warmer water: light blue

Launched in 1999
Planned to end in Sep 2023

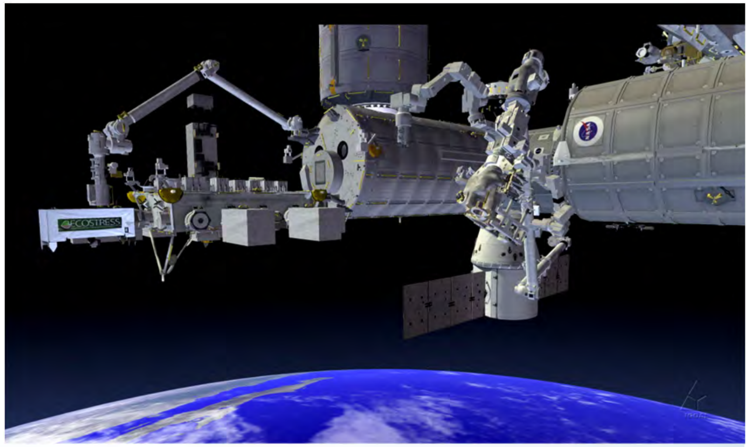
Credit:
NASA JPL and U.S./Japan ASTER Science Team



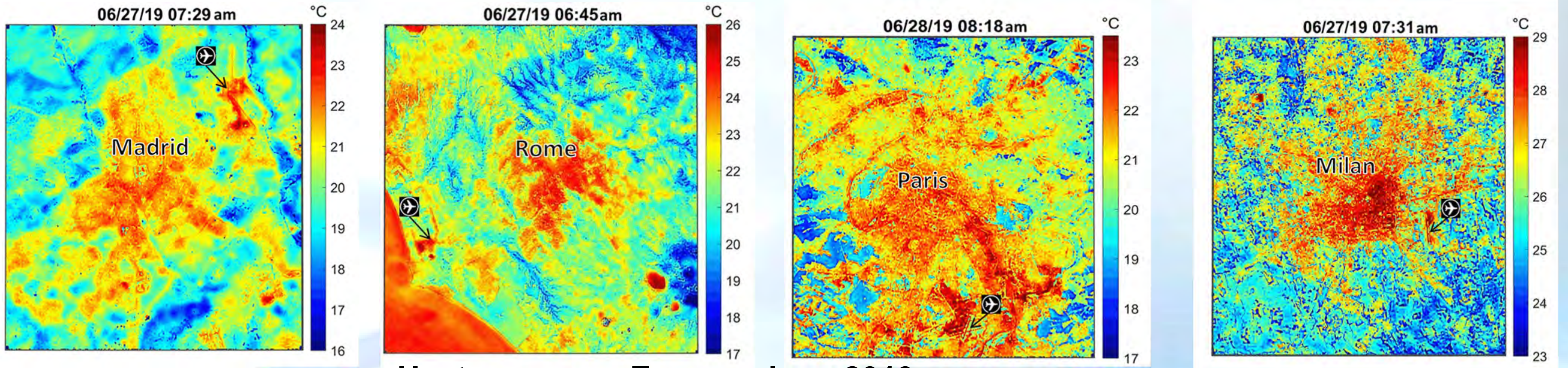
ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on the International Space Station (ISS)

- Prototype HyspIRI **Thermal Infrared** Radiometer
  5 spectral bands in the 8-12.5 µm range +1.6 µm
  - Spatial resolution ~70 m
  - **Advantage** over Terra/ASTER – more frequent observations
- Science objectives
  - Identify critical thresholds of water use and water stress in key biomes (e.g., tropical/dry transition forests, boreal forests)
  - Detect the timing, location, and predictive factors leading to plant water uptake decline and cessation over the diurnal cycle
  - Measure agricultural water consumptive use over continental US at spatiotemporal scales applicable to improving drought estimation accuracy



Credit: NASA/JPL-Caltech

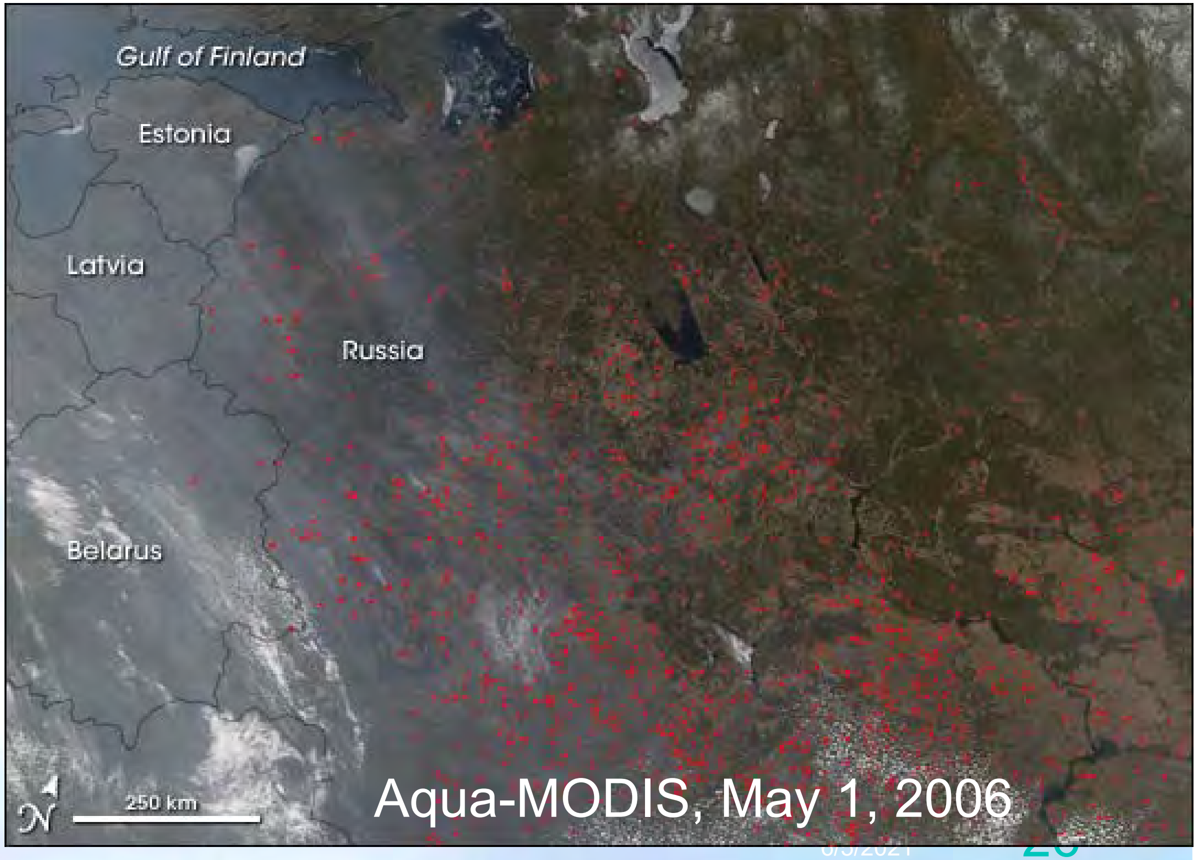


Heatwave over Europe: June 2019

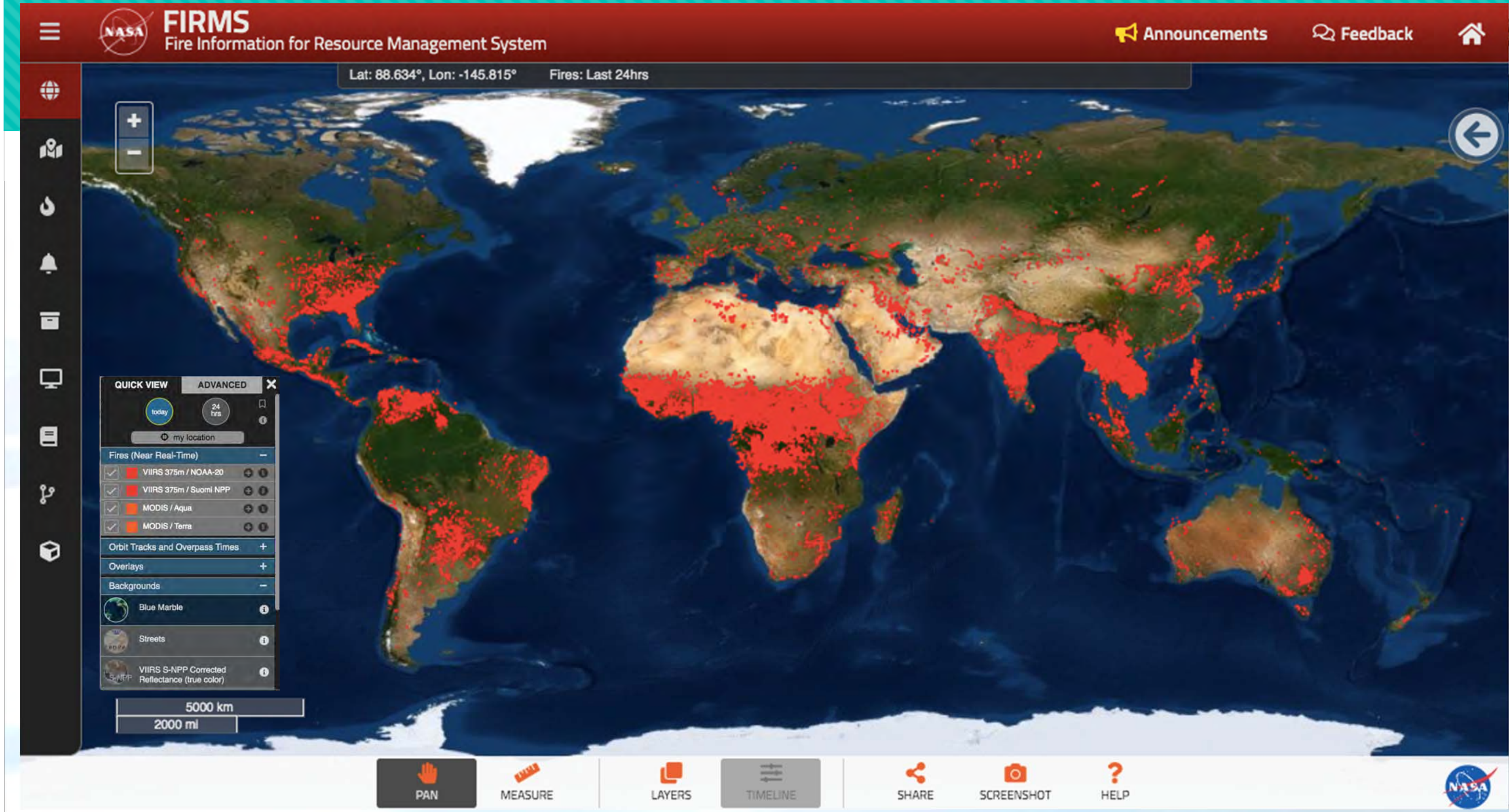
Monitoring Fires

- Forest and agricultural fire hot spots are detected using 4 μm band
- Done through smoke
- Used in fire fighting

https://earthdata.nasa.gov/earth-observation-data/near-real-time/rapid-response



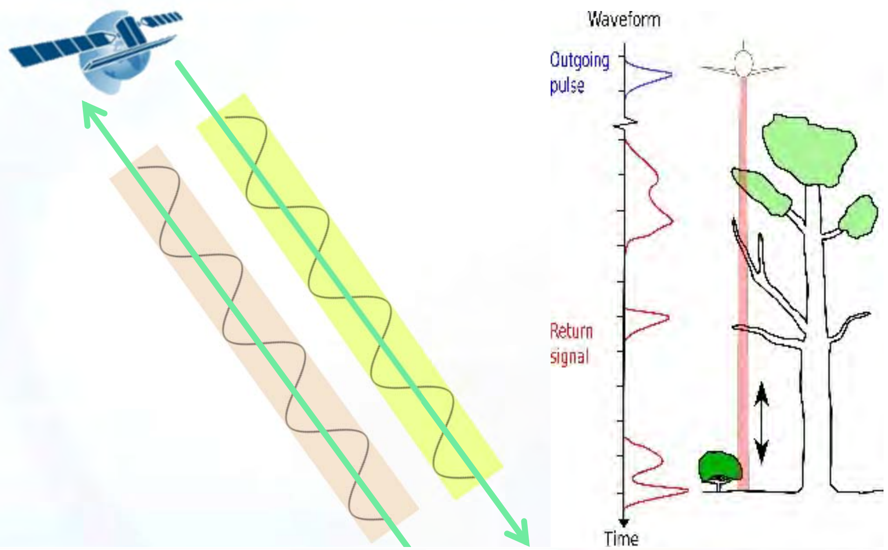
Global Fires from MODIS: Last 24 hours

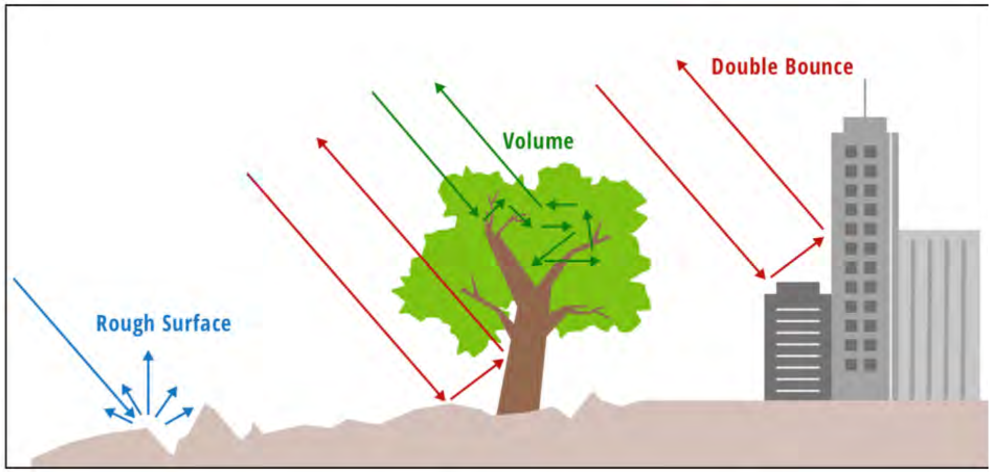


https://firms.modaps.eosdis.nasa.gov/map/

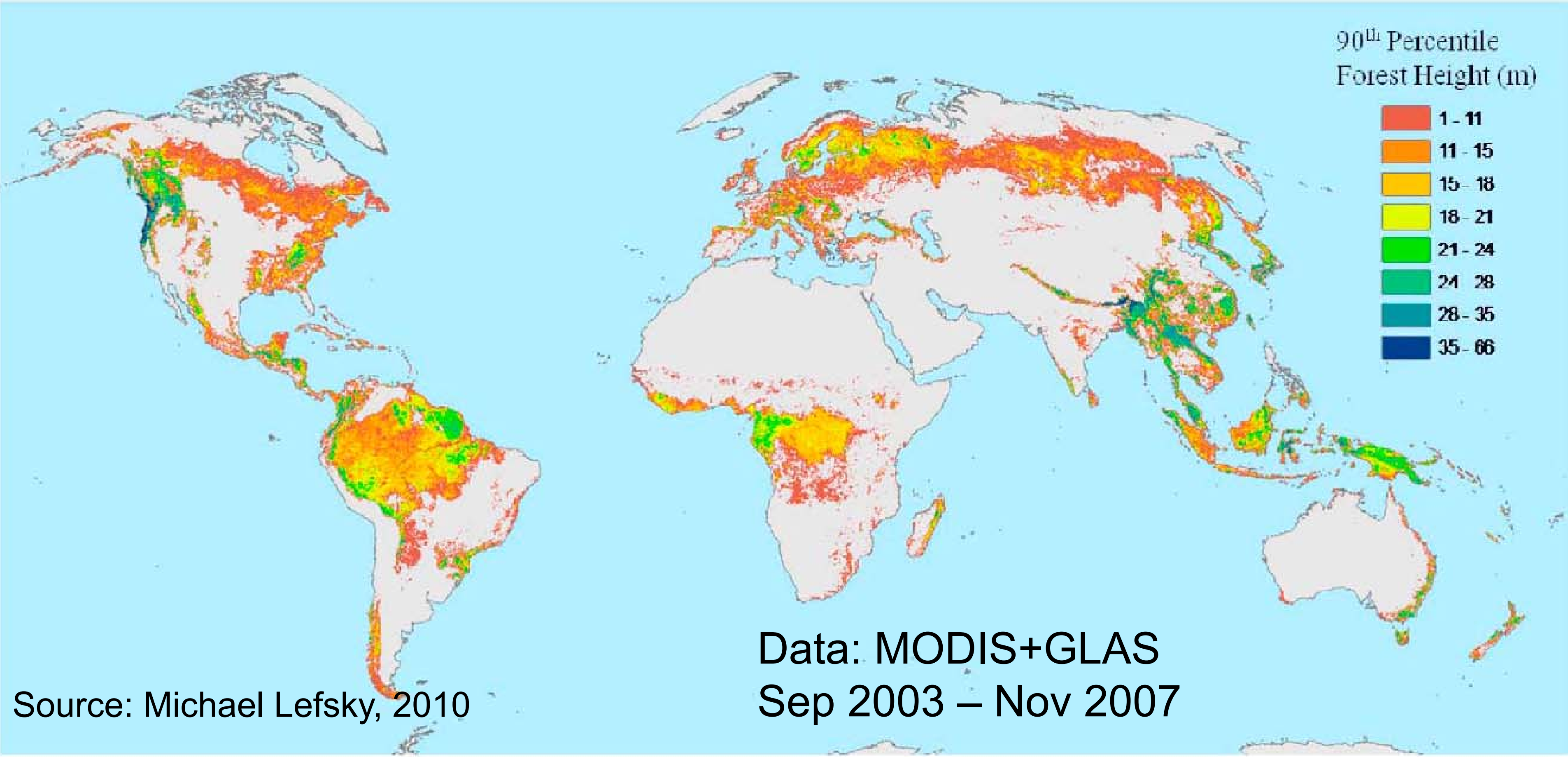
Active Remote Sensing: Near-IR (Lidars) and Microwave (Radars)

- RADAR: ***Ra****dio* ***D****etection* ***a****nd* ***R****anging*
- LIDAR: ***Li****ght* ***D****etection* ***a****nd* ***R****anging*
  - Active systems: generate, transmit pulses and capture target echo signal by the receiver
  - Measure the time it takes to return to its source
  - Day-night capabilities
  - RADAR: all-weather sensor (backscatter signal)
  - LIDAR: clear conditions sensor (return signal – waveform)





Forest Canopy Height From Lidar

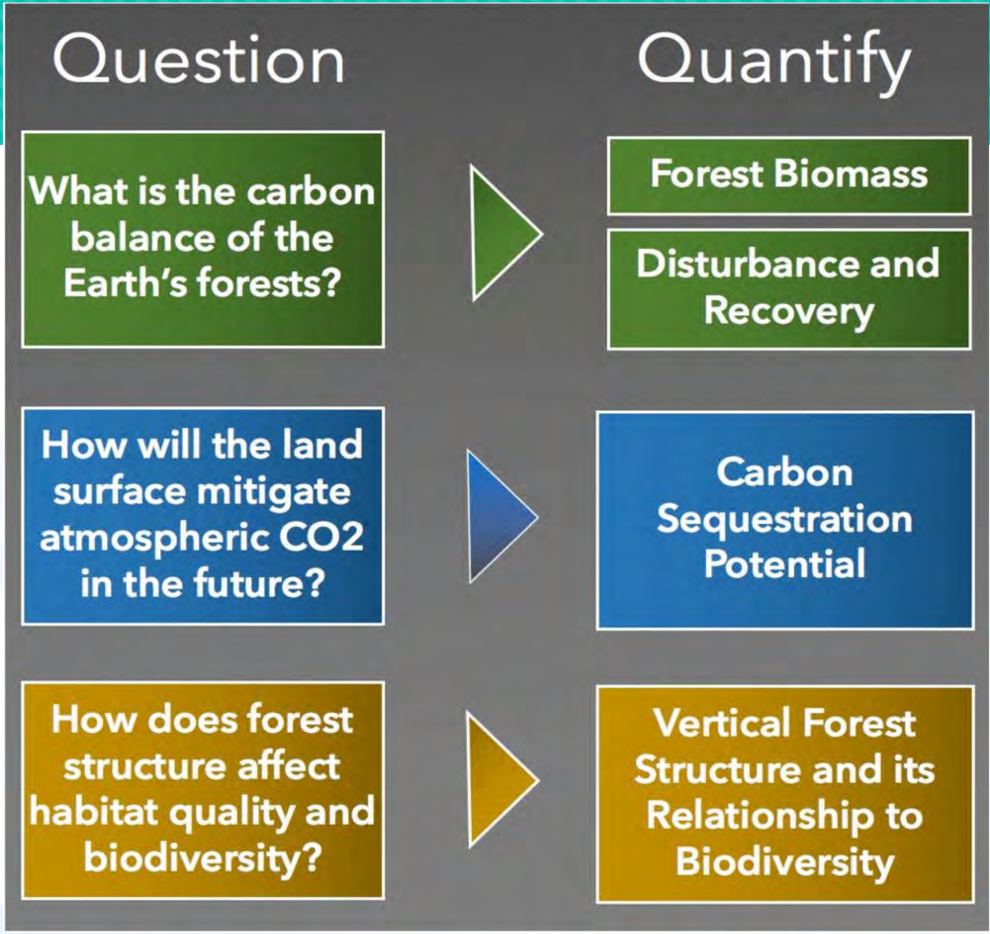


Source: Michael Lefsky, 2010

Data: MODIS+GLAS
Sep 2003 – Nov 2007

Geoscience Laser Altimeter System (GLAS) on ICESAT

Global Ecosystem Dynamics Investigation
NASA GEDI mission



https://gedi.umd.edu/science/objectives-overview/

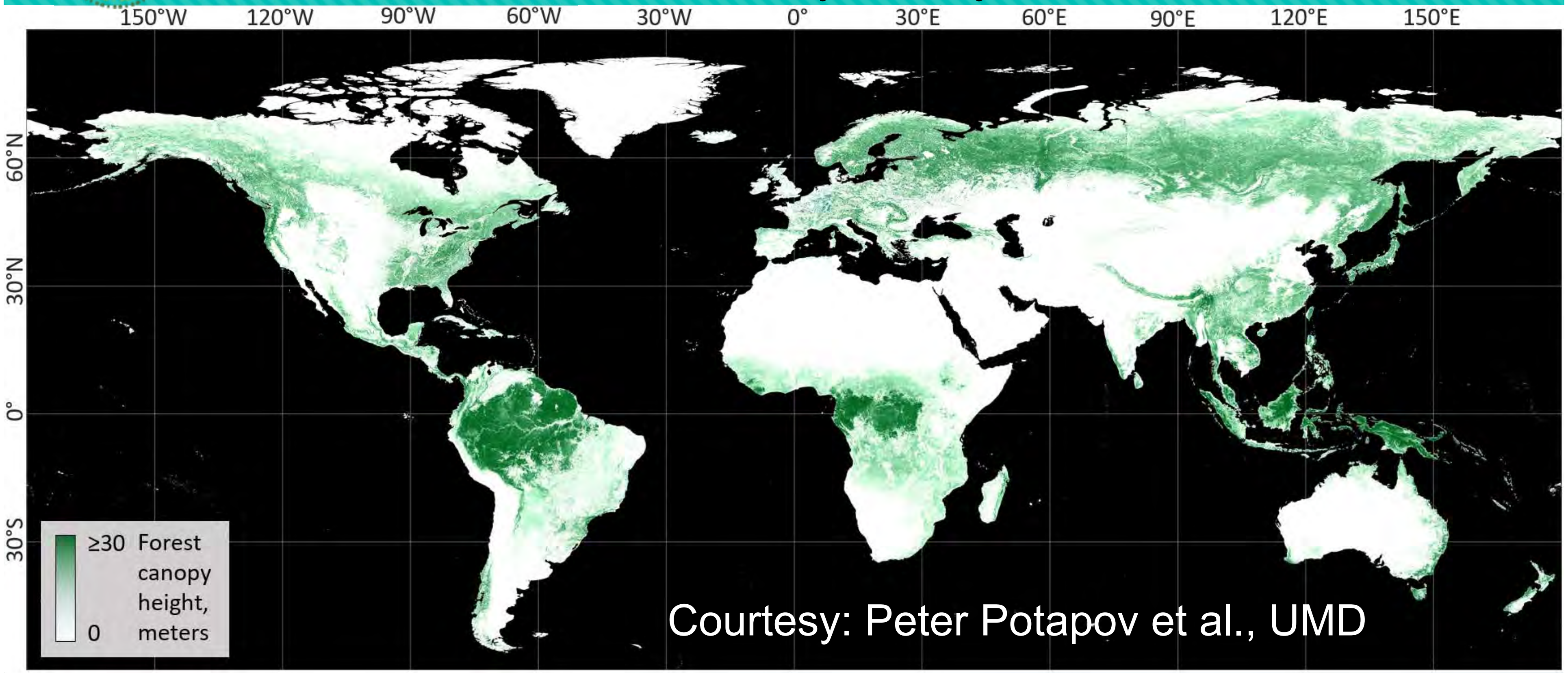
"GEDI will provide a vertical record, not only of how tall trees are, but how much canopy material there is at any height" (Ralph Dubayah, GEDI principal investigator, U. Maryland)

High resolution laser ranging observations

- three lasers produce eight parallel tracks of observations
- each laser fires 242 times per second and illuminates a 25 m spot (a footprint) on the surface

Forest Canopy Height: 2019

Global Land Analysis & Discovery at University of Maryland



https://glad.umd.edu/dataset/gedi

https://glad.earthengine.app/view/global-forest-canopy-height-2019

Integration of the Global Ecosystem Dynamics Investigation (GEDI) lidar forest structure measurements and **Landsat analysis-ready data** time-series

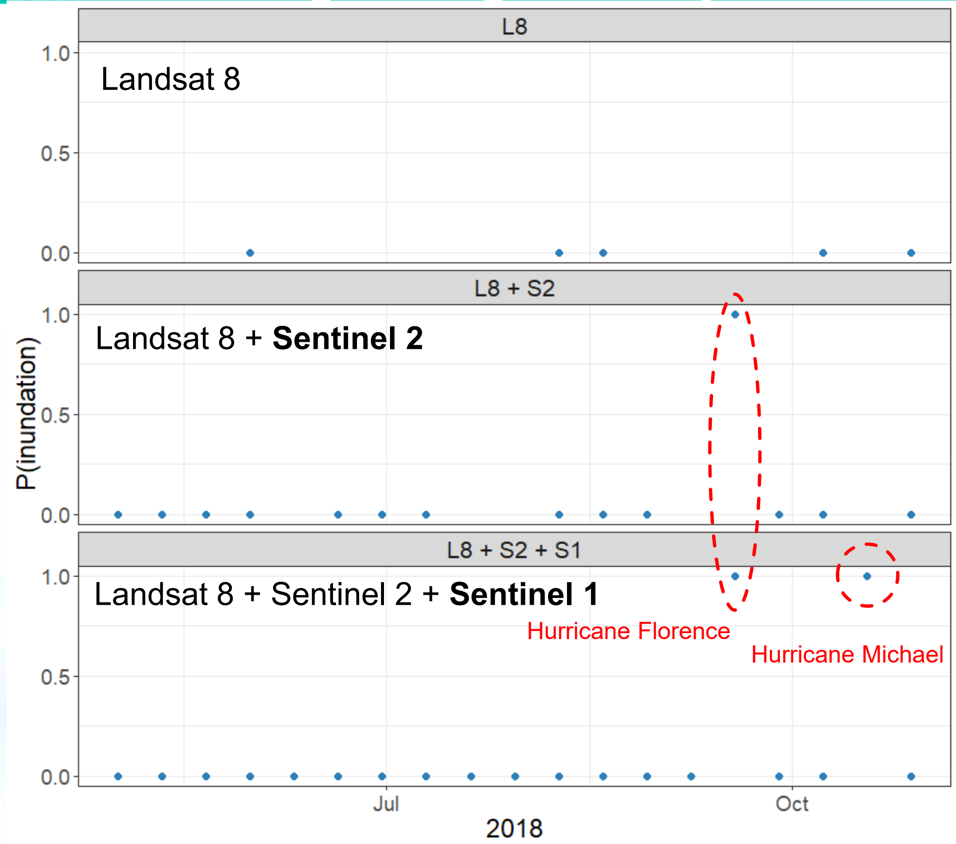
Merging Optical (Landsat, Sentinel 2) and Active Microwave (Sentinel 1 Radar) Data: Mapping Inundation

PI: Cheng Huang, U. Maryland

North Carolina agricultural town ...

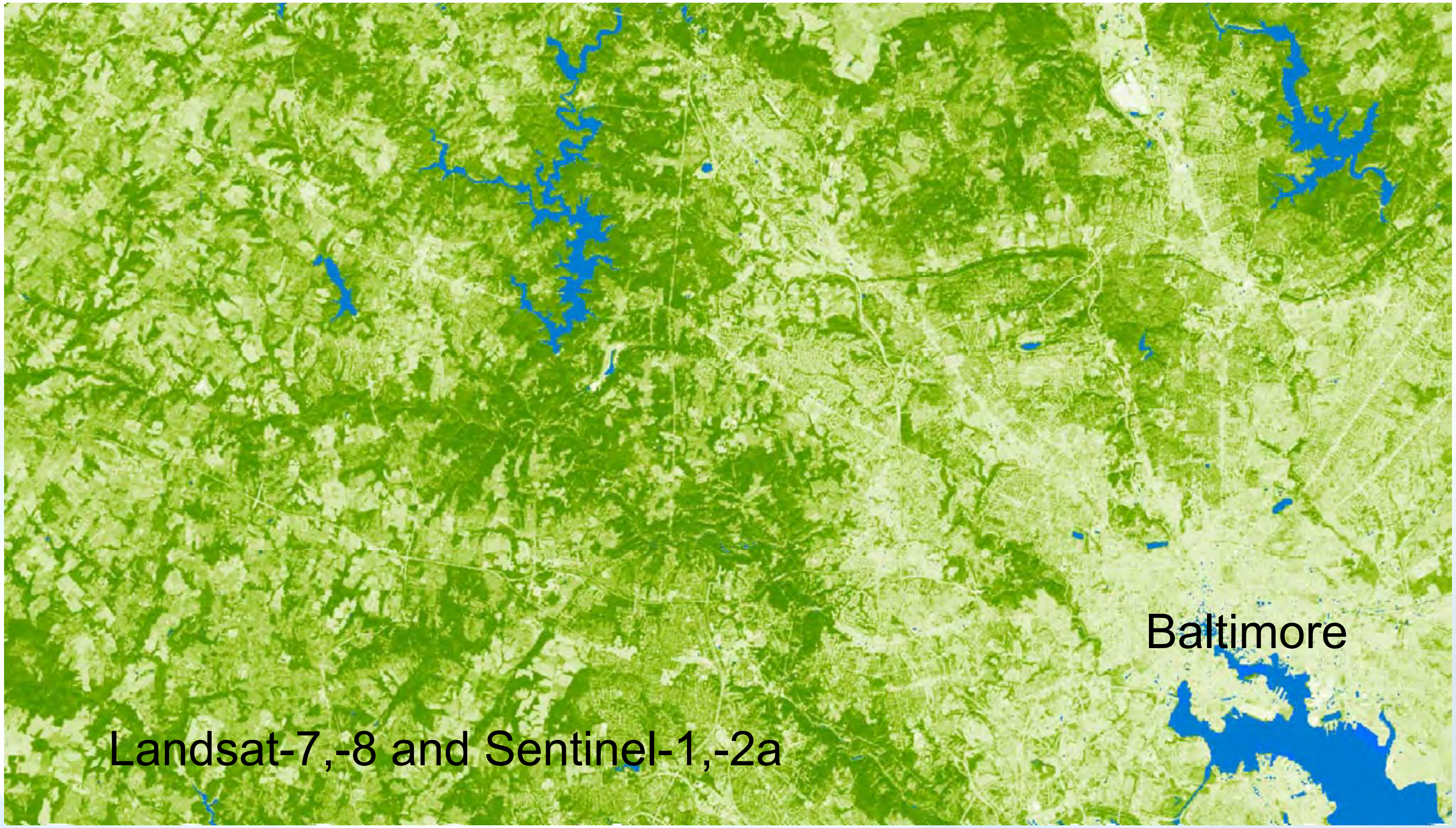
nbcnews.com

Hurricane Michael damage: PHOTOS ...



Two flooding events over crop fields in N. Carolina: 1) Hurricane Florence in Sep 2018 - captured by L8 + S2, 2) Michael in Oct 2018 Hurricane L8+S2+S1. These events are not captured by L8 data alone.

Tree Canopy Cover Estimated from Landsats and Sentinel-1, 2

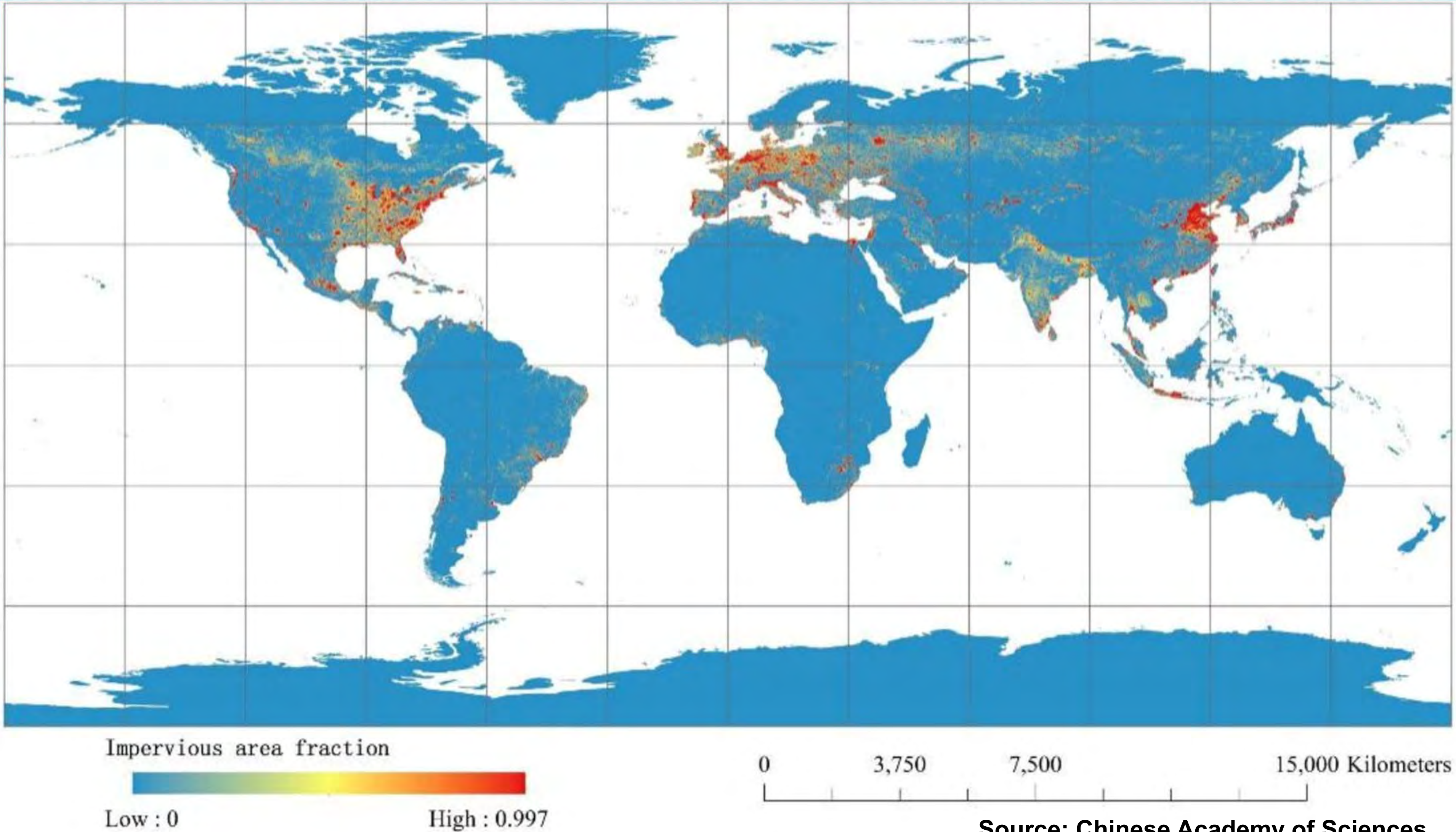


Courtesy: Saurabh Channan, UMD

Landsat8 filled most of the gaps caused by SLC off, cloud, cloud shadow, but still some gaps remained.

Combining with Sentinel-1 and -2 removed the remaining gaps.

Global Fraction of Impervious Cover



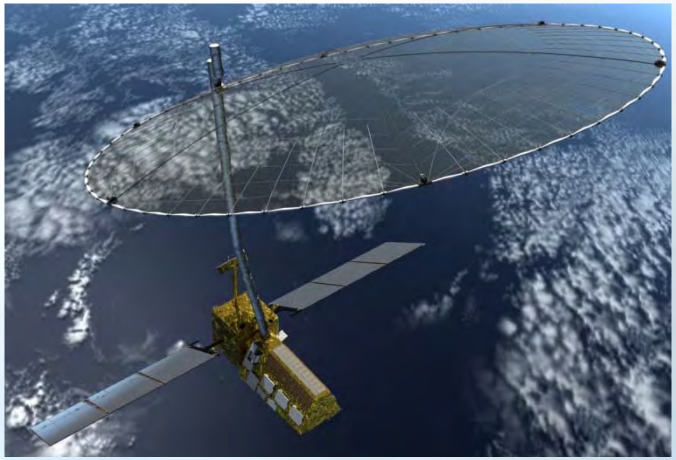
Source: Chinese Academy of Sciences

Derived from Landsat 8 and Sentinel-1 SAR data (2015-2016)

NASA-ISRO SAR Mission (NISAR)

- A joint project between NASA and Indian Space Research Organization (ISRO) to co-develop and launch a **dual frequency** SAR satellite
- Will measure Earth's changing ecosystems, dynamic surfaces, and ice masses providing information about biomass, natural hazards, sea level rise, and groundwater
- SAR instruments:
  - **L-band** (24 cm wavelength) polarimetric SAR, to be produced by NASA
  - **S-band** (12 cm wavelength) polarimetric SAR, to be produced by ISRO
- Planned launch: Sep 2022

NISAR
NASA - ISRO SAR Mission



https://nisar.jpl.nasa.gov/

[Source: NASA JPL]

ESA SAR P-band BIOMASS Mission

- BIOMASS satellite is part of ESA's Living Planet Programme
- Will provide global maps of the amount of carbon stored in the world's forests
- SAR instruments:
  - **P-band** (~70 cm) – first in space!
- Planned launch: Oct 2023

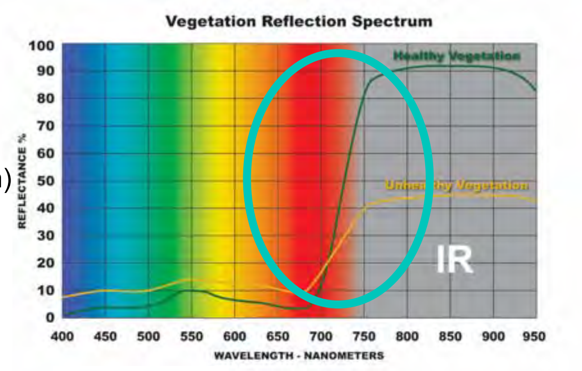
The SAR antenna is based on a large deployable reflector (12 m circular projected aperture)

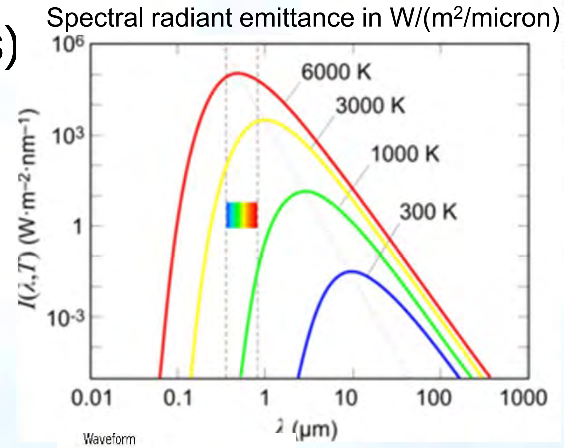
https://earth.esa.int/web/guest/missions/esa-future-missions/biomass
https://www.sciencedirect.com/science/article/pii/S0034425717301943

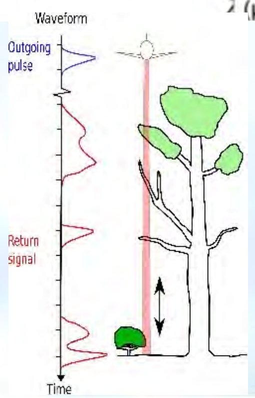
Multi-spectral Land Remote Sensing: Summary

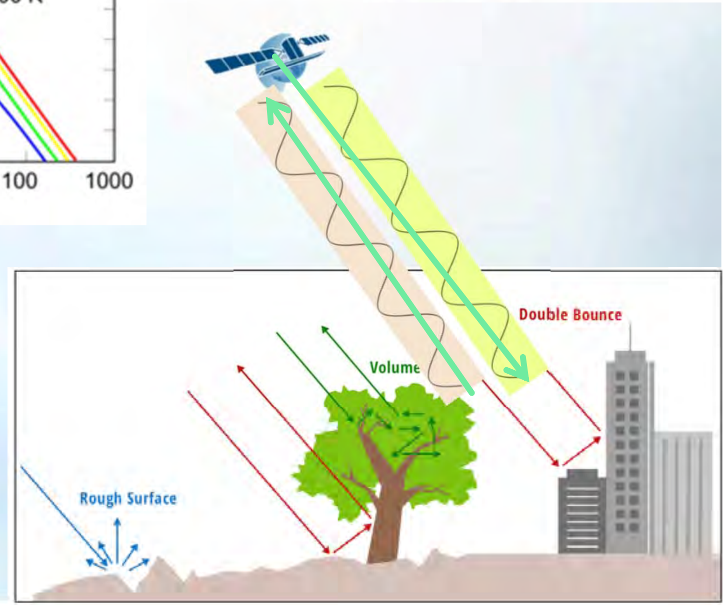
- Passive
  - Visible – Near-IR (vegetation)
  - Thermal IR (heat islands)
  - Middle IR (fires)

- Active
  - Microwave (radars)
  - Near-IR (lidars)

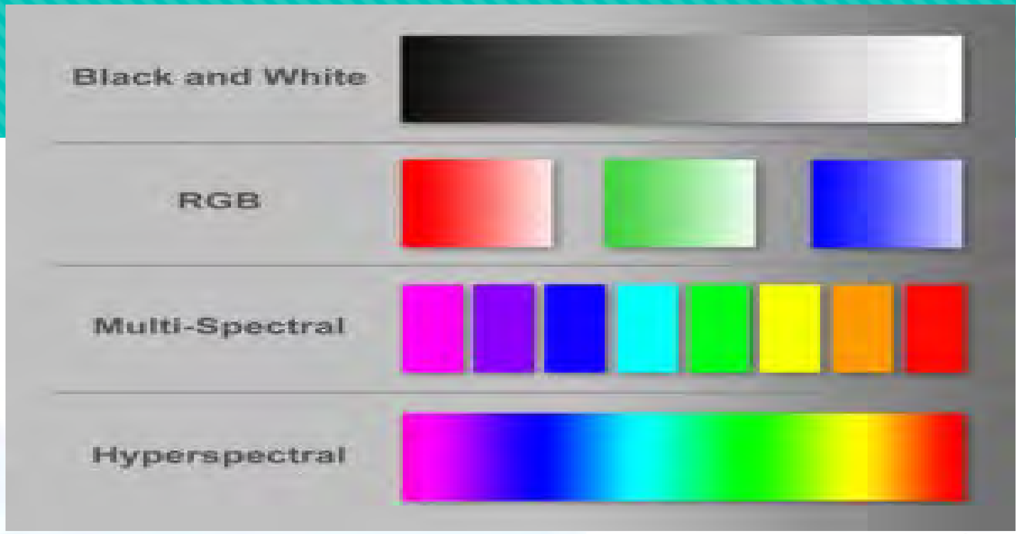


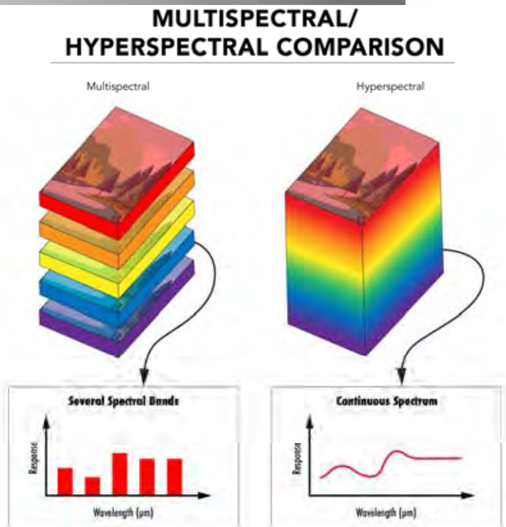


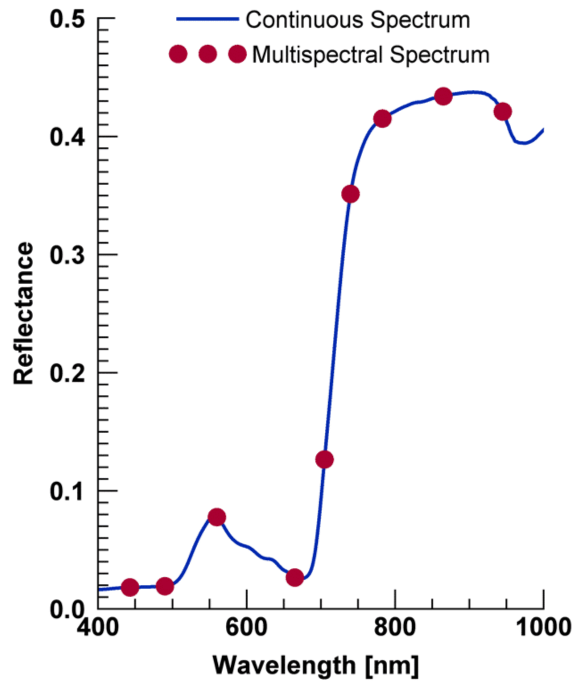




From Multispectral to Hyperspectral







- **Multispectral imagery**
  - 3 -10 discrete broader bands
- **Hyperspectral imagery**
  - many more (>200) much narrower bands (0.1-0.2µm)

Contiguous hyperspectral reflectance spectrum compared to the VNIR center wavelengths of ESA's multispectral Sentinel-2

HS remote sensing provides detailed information about any object because of narrowband information acquisition

For each pixel a contiguous reflectance spectrum

Hyperspectral Imagery in Agriculture

Hyperspectral imaging extends the human vision and can capture issues that are not visible to agronomists

- **MS** imagery is unlikely to classify weeds, crop diseases, pests, nutrient deficiencies
- **HS** imagery classifies type of weeds, wild vegetation and crop varieties

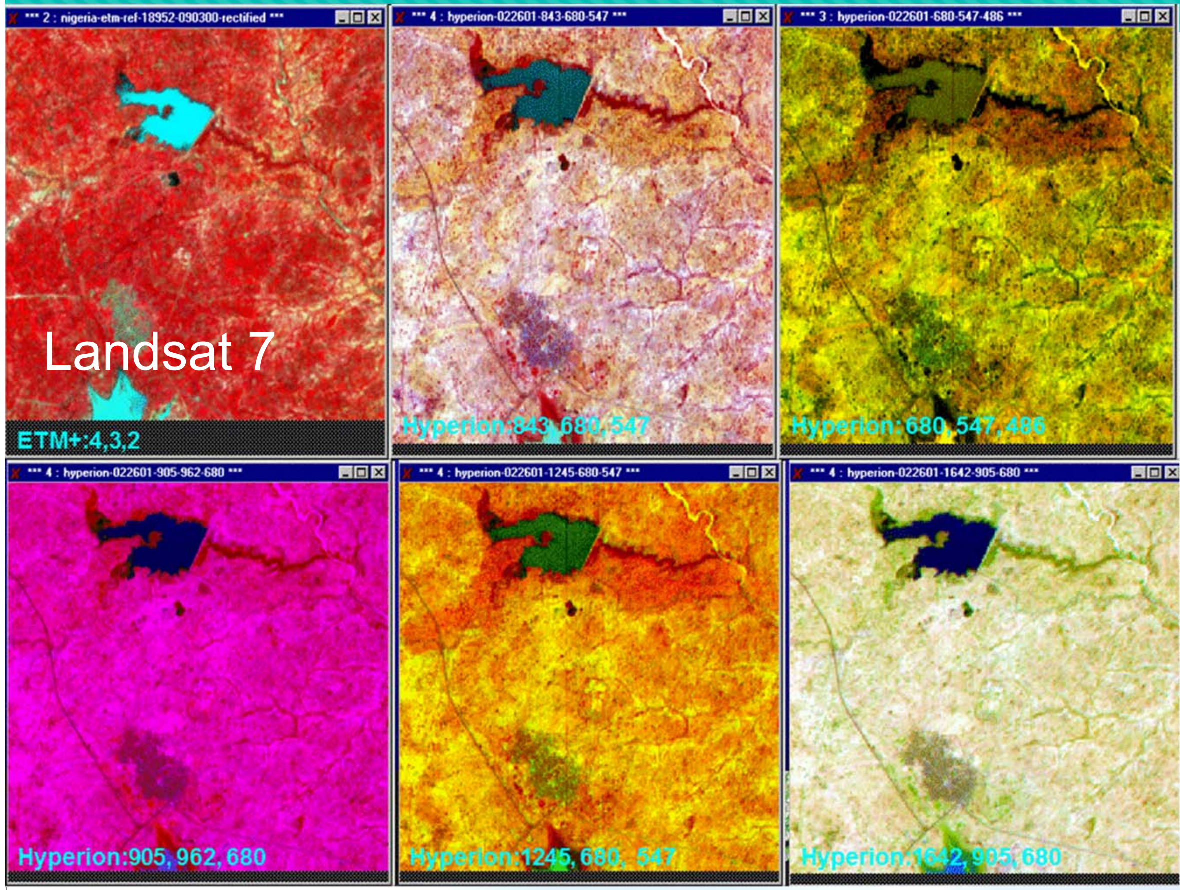
- **MS** cameras can measure generic characteristics about plant
  - Healthy/not healthy
- **HS** images can diagnose the exact reason for that state

Sugarcane varieties, hyperspectral image

HS correlate spectral signature with changes in the plant physiology

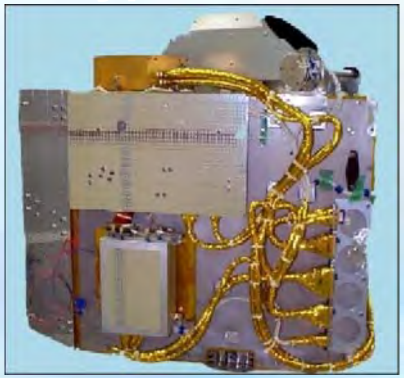
https://medium.com/remote-sensing-in-agriculture/multispectral-vs-hyperspectral-in-agriculture-9a2d96777031

The First Hyperspectral Imager in Space
EO-1/Hyperion



Nov 2000-Mar/2017

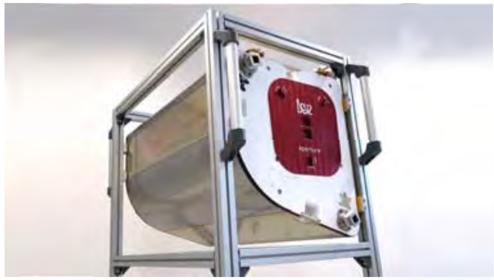
Hyperion

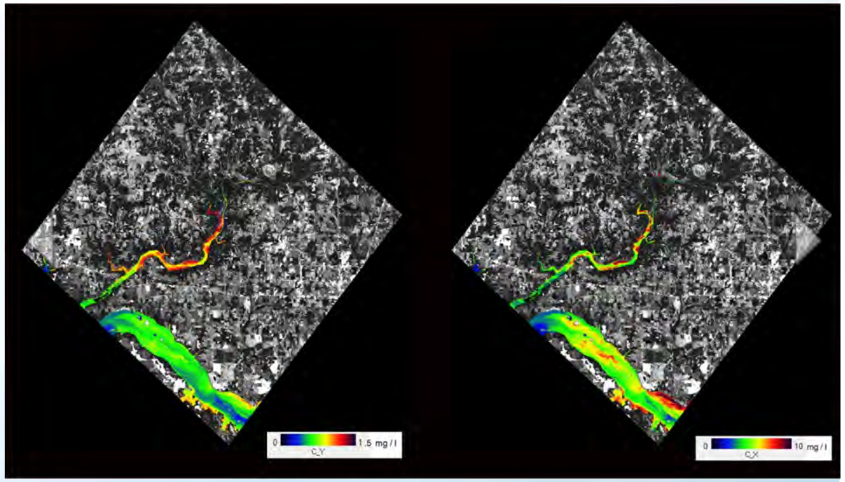


(Source: Prasad Thenkabail, USGS)

DLR Earth Sensing Imaging Spectrometer (DESIS) on ISS

- Launched to the International Space Station (ISS) from Cape Canaveral on **29 June 2018**
- Deployed in **Aug 2018** to observe the Earth and provide **hyperspectral data** to support scientific,
- DESIS has **235 spectral channels** with ground resolution 30m
- Can point forwards, backwards and to the sides





02 October 2018 water quality analysis

https://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10212/332_read-28665/#/gallery/30169

Current trends in Land Remote Sensing

- Multi-source mid-resolution land imaging using virtual constellation of available space assets with compatible characteristics (e.g., Landsat and Sentinel-2)
- Wider use of very high-resolution commercial data from constellations (e.g., Planet Lab and Maxar)
- Synergistic use of passive optical and active microwave (radar) data (e.g., Landsat, Sentinel-2 with Sentinel-1)
- Intensified use of machine learning & cloud computing

Additional Resources

- https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11139/2528945/Monitoring-forest-disturbance-using-change-detection-on-synthetic-aperture-radar/10.1117/12.2528945.short?SSO=1
- https://core.ac.uk/download/pdf/79111495.pdf
- https://nisar.jpl.nasa.gov/
- https://earth.esa.int/web/guest/missions/esa-future-missions/biomass
- https://www.sciencedirect.com/science/article/pii/S0034425717301943
- https://www.youtube.com/watch?v=uSESVm59uDQ
- https://grindgis.com/data/lidar-data-50-applications
- https://lidarradar.com/info/advantages-and-disadvantages-of-lidar
- https://gedi.umd.edu/science/objectives-overview/
- https://glad.umd.edu/dataset/gedi
- https://glad.earthengine.app/view/global-forest-canopy-height-2019
- https://medium.com/remote-sensing-in-agriculture/multispectral-vs-hyperspectral-in-agriculture-9a2d96777031

Thanks to Aristotle U.

TAT: 8 years and counting!

The moment of ESA-NASA TAT Prague Agreement