Land-Cover and Land-Use Change Program

Multispectral Satellite Missions for Land-Cover and Land-Use Monitoring: An Overview

DR. GARIK GUTMAN

LCLUC PROGRAM MANAGER

NASA HQ, WASHINGTON DC

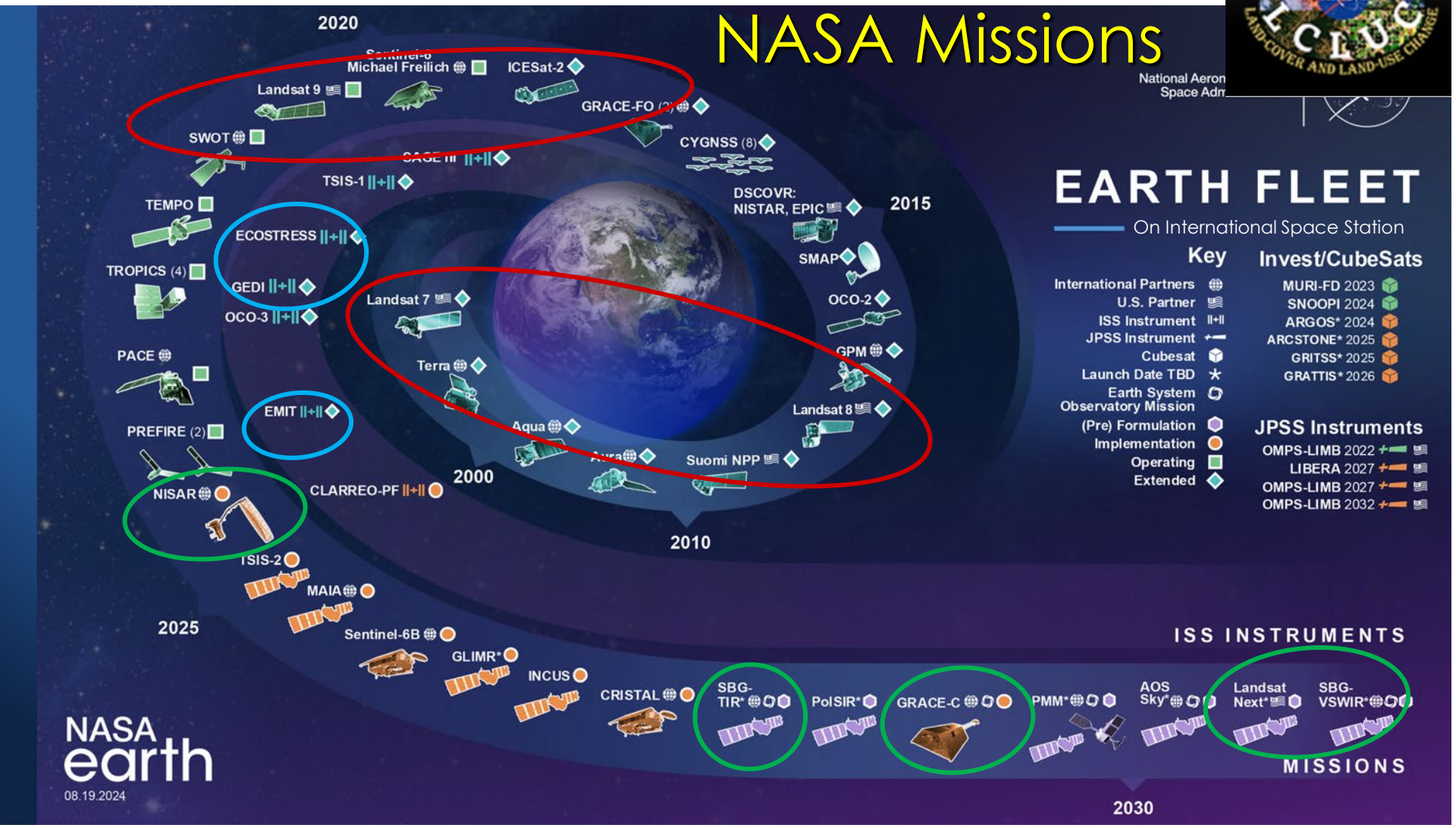
The NASA LCLUC Program

LCLUC is an interdisciplinary scientific theme within NASA's Earth Science program. The ultimate vision of this program is ***to develop the capability for periodic global inventories of land use and land cover from space, to develop the scientific understanding and models necessary to simulate the processes taking place, and to evaluate the consequences of observed and predicted changes***

- Characterizing Land Cover
- Quantifying LC Change
- Drivers of LCLUC
  - Natural Drivers
  - Anthropogenic Drivers
    - Socio-Economic & Political
    - Landscape Modification
- Impacts of LCLUC
  - Carbon Cycle
  - Surface Hydrology
  - Atmospheric circulation
  - Social Systems
  - Food, Energy, Water
- Scenarios of Future Change

NASA Earth Science Questions

- Detection/Monitoring
  - What changes are occurring in global land cover and land use, and what are their causes?
- Impacts
  - What are the consequences of land- cover and land-use change for the sustainability of ecosystems and economic productivity?


NASA Missions
LCLUC
LAND-COVER AND LAND-USE CHANGE
National Aeron
Space Adm
2020
Michael Freilich
ICESat-2
Landsat 9
GRACE-FO
SWOT
CYGNSS (8)
TSIS-1
TEMPO
DSCOVR:
NISTAR, EPIC
2015
ECOSTRESS
SMAP
TROPICS (4)
GEDI
Landsat 7
OCO-2
OCO-3
PACE
Terra
GPM
EMIT
Landsat 8
PREFIRE (2)
Aqua
Suomi NPP
2000
NISAR
CLARREO-PF
2010
TSIS-2
MAIA
2025
Sentinel-6B
GLIMR*
INCUS
CRISTAL
SBG-
TIR*
PolSIR*
GRACE-C
PMM*
AOS
Sky*
Landsat
Next*
SBG-
VSWIR*
ISS INSTRUMENTS
MISSIONS
2030
EARTH FLEET
On International Space Station
Key
International Partners
U.S. Partner
ISS Instrument
JPSS Instrument
Cubesat
Launch Date TBD
Earth System
Observatory Mission
(Pre) Formulation
Implementation
Operating
Extended
Invest/CubeSats
MURI-FD 2023
SNOOPI 2024
ARGOS* 2024
ARCSTONE* 2025
GRITSS* 2025
GRATTIS* 2026
JPSS Instruments
OMPS-LIMB 2022
LIBERA 2027
OMPS-LIMB 2027
OMPS-LIMB 2032
NASA
earth
08.19.2024

NASA Satellite Missions for Land Imaging

Landsat – joint with USGS
NISAR – joint with ISRO
Suomi-NPP – joint with NOAA

Systematic Missions - Observation of Key Earth System Interactions by Passive Optical Systems

coarse resolution

Terra 12/18/99 — **ASTER** **MODIS**

Aqua 5/3/02

Suomi-NPP 10/28/11 — **VIIRS**

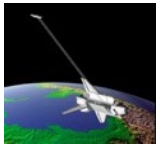
moderate-→ high resolution

Landsat 8 2/11/13

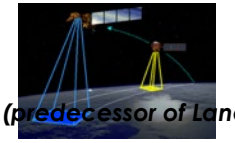
Landsat 9 9/27/21

Landsat Next Nov 2031

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



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



ALI (predecessor of Landsat-8)

Earth Observing EO-1

Hyperion – first hyperspectral in space
11/21/00-3/30/2017

International Space Station (ISS)

ECOSTRESS (thermal IR)
GEDI (Lidar) Active optical
EMIT (Hyperspectral)

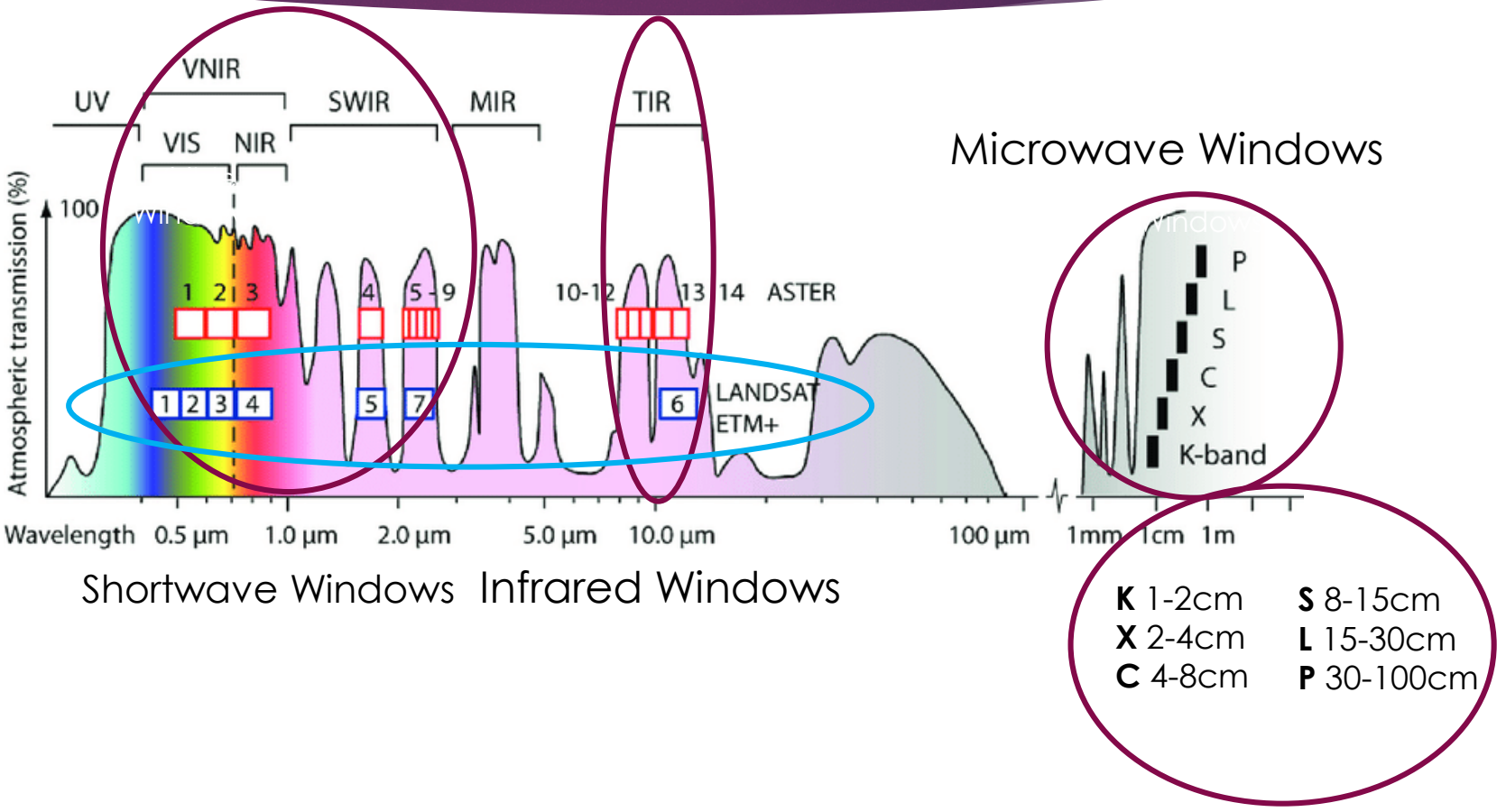
Deployed in 2018 and 2022

Radars

Active Microwave

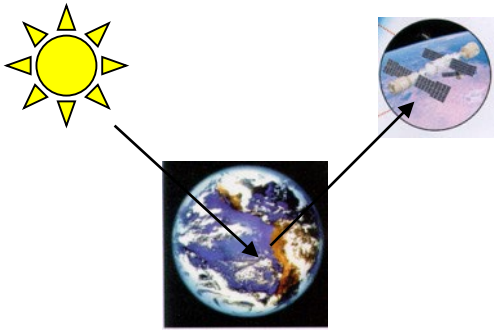
NISAR 2025

Atmospheric Windows for Surface Remote Sensing

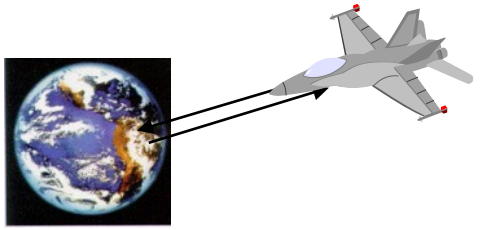


Remote Sensing: Passive - Active

- Passive Systems
  - Use natural energy sources: Sun
  - Reflected or emitted energy
- Active Systems
  - Have their own energy source
  - Radar, Lidar
  - Radar – all-weather sensor
  - Lidar – optical, clear conditions



Passive, Reflected

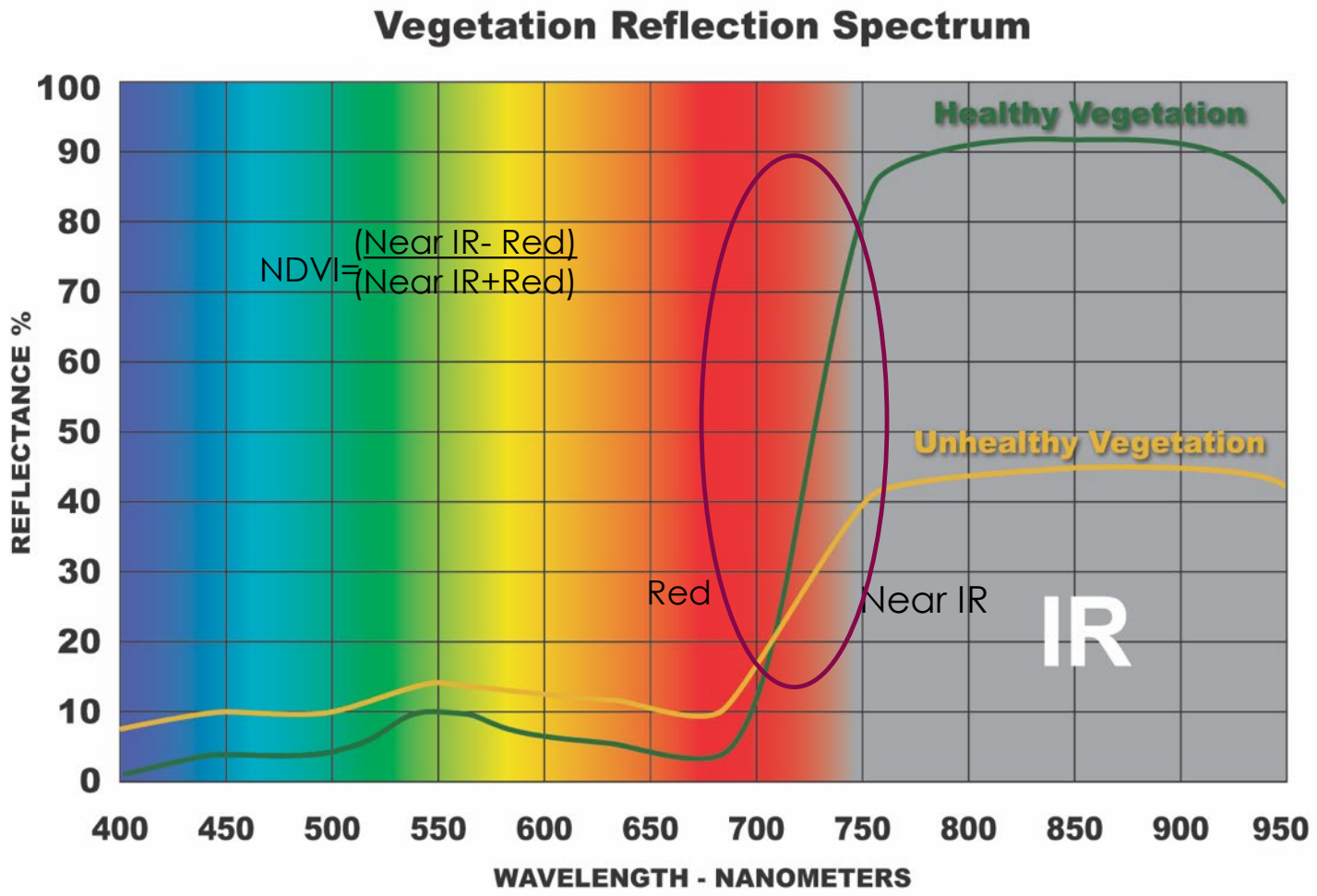


Active

Some Passive Optical Remote Sensing Applications

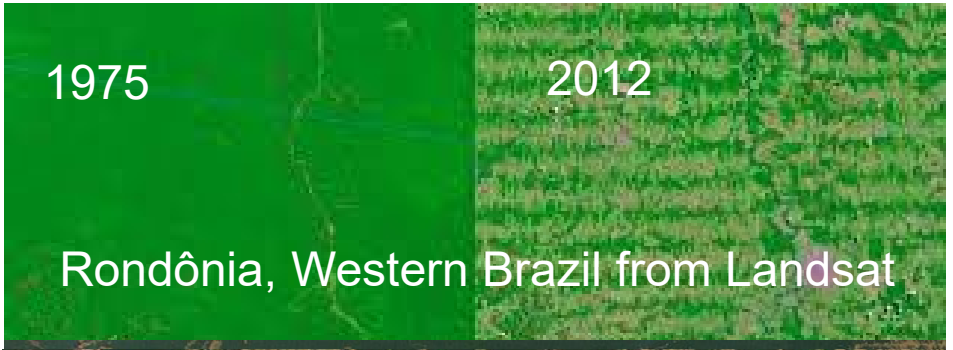
- Forest Change Detection and Monitoring
- Urbanization Change Detection and Monitoring
- Agricultural Change Detection and Monitoring

Green Vegetation vs Non-Green Vegetation or Soil

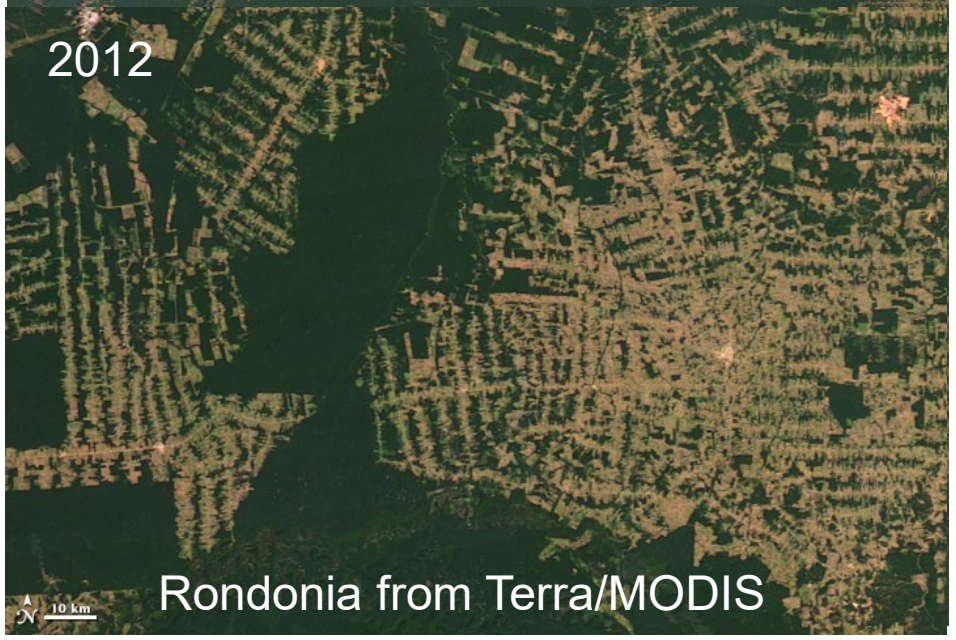


Deforestation

- Over half of the tropical forests worldwide have been destroyed since the 1960s
- Every second more than one hectare of tropical forests is destroyed or drastically degraded
- Deforestation occurs when forests are converted to non-forest uses, such as agriculture and road construction



Rondônia, Western Brazil from Landsat

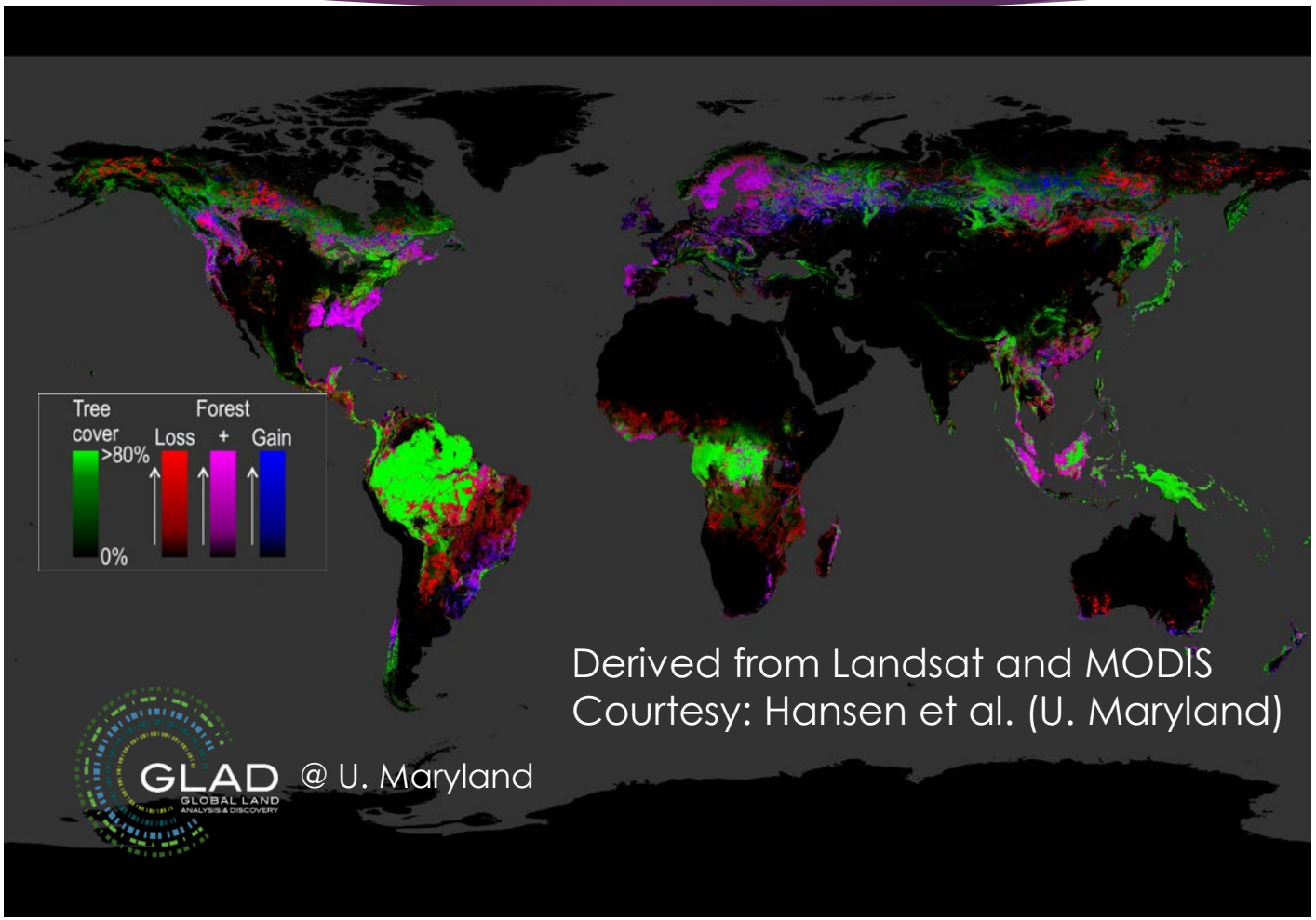


Rondonia from Terra/MODIS

Fishbone patterns →

- https://www.youtube.com/watch?v=hllU9NEcJyg

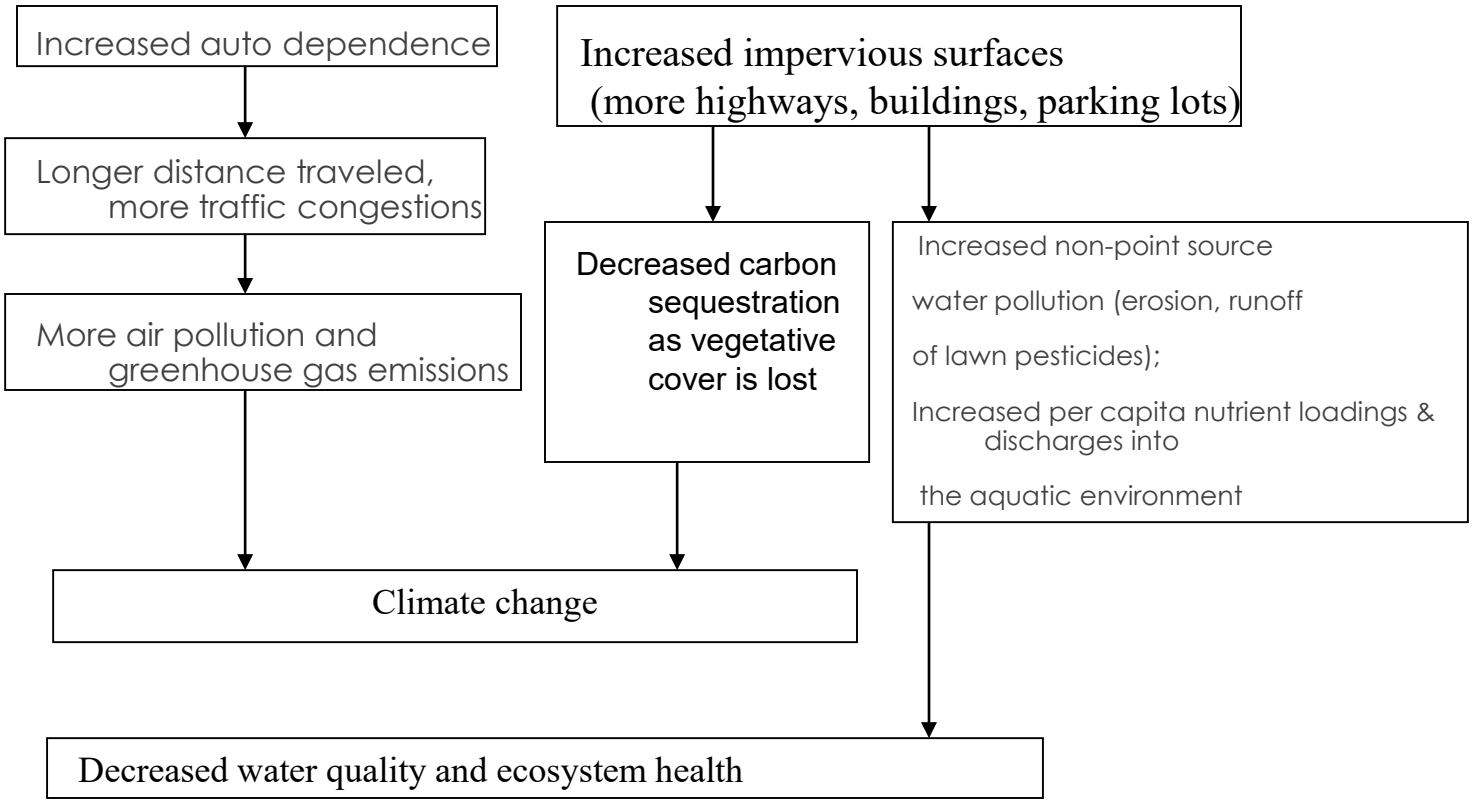
Tree Cover Extent and Forest Loss and Gain: 2000-2014

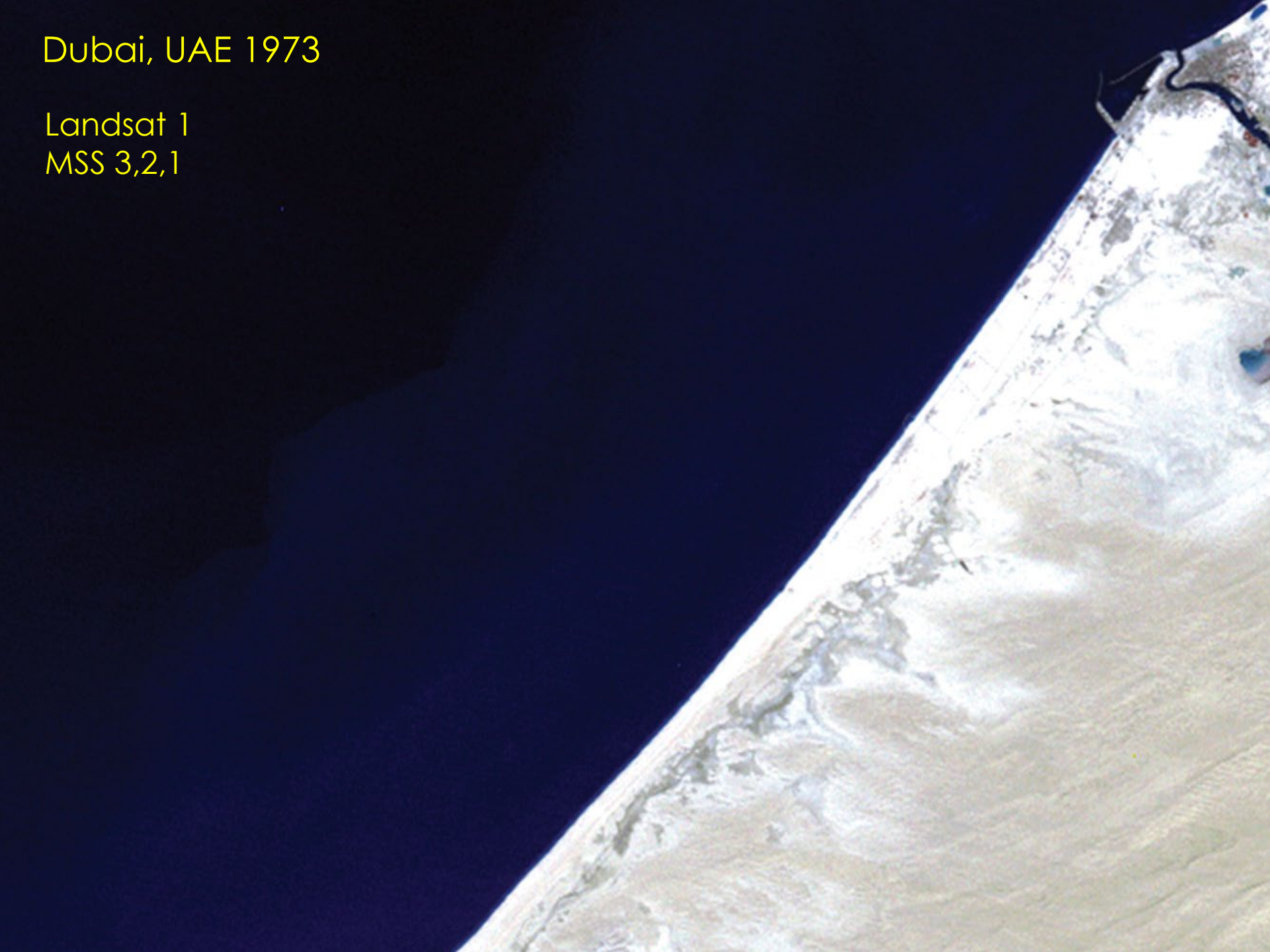


Urbanization and its Impacts

- Land cover
- Air/water Pollution
- Emissions
- Local climate change
  - Urban heat island effect

Increased Urban Sprawl



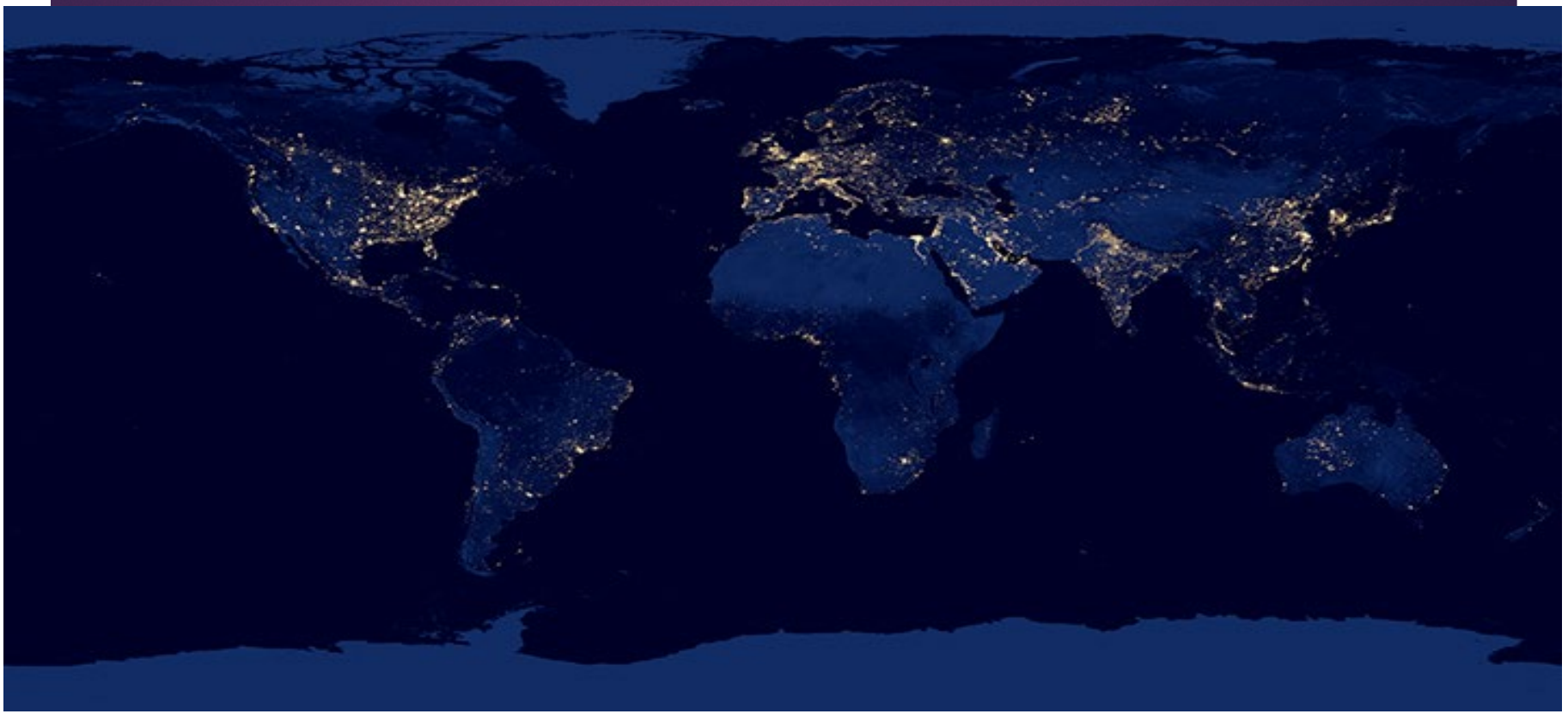

Dubai, UAE 1973
Landsat 1
MSS 3,2,1


Dubai, UAE 1990
Landsat 5
TM 4,3,2


Dubai, UAE 2006
Landsat 7
ETM+ 4,3,2

Night Lights

VIIRS/Suomi-NPP

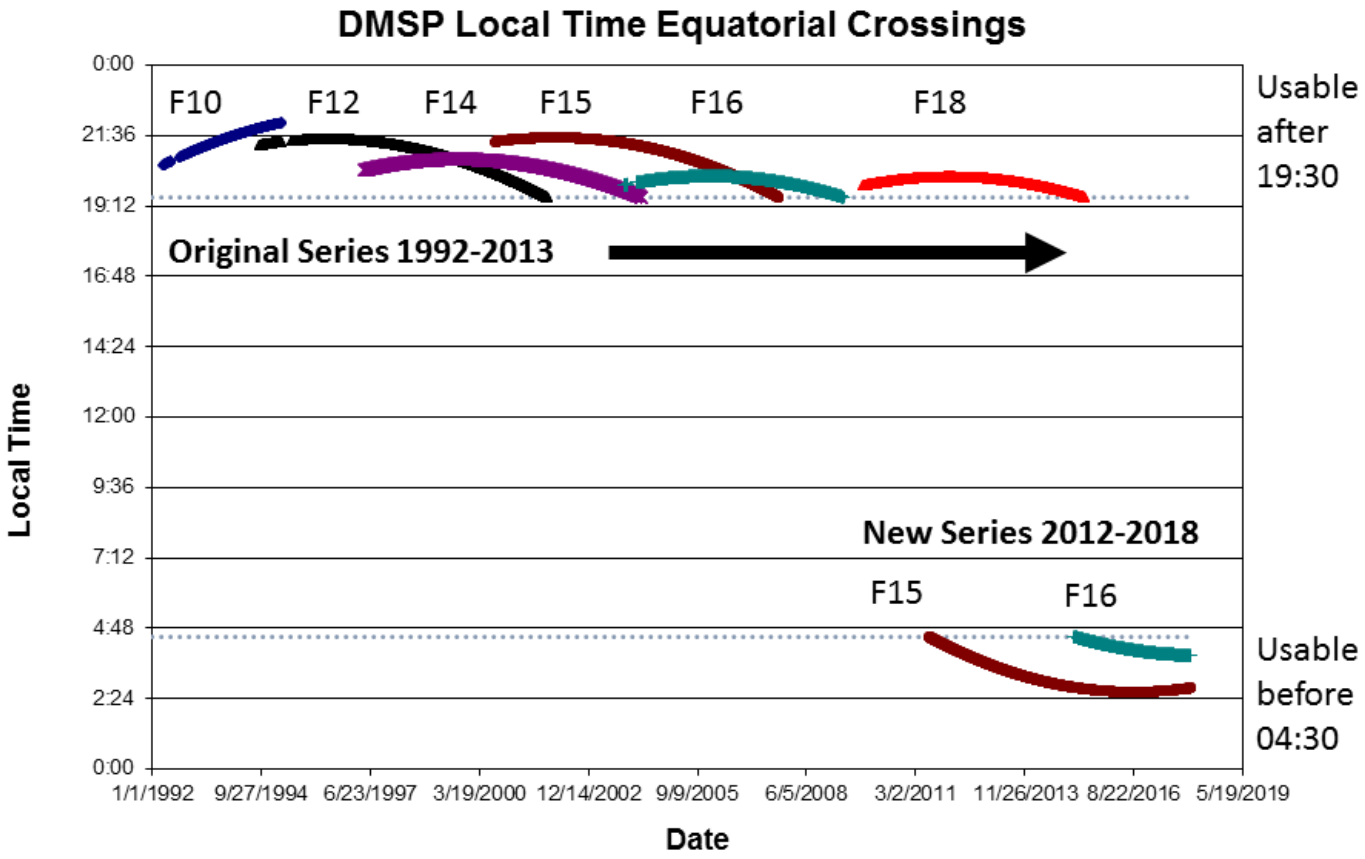


VIIRS (742 m^2 /14 bit as compared to OLS 5km^2/ 6 bits on DMSP)

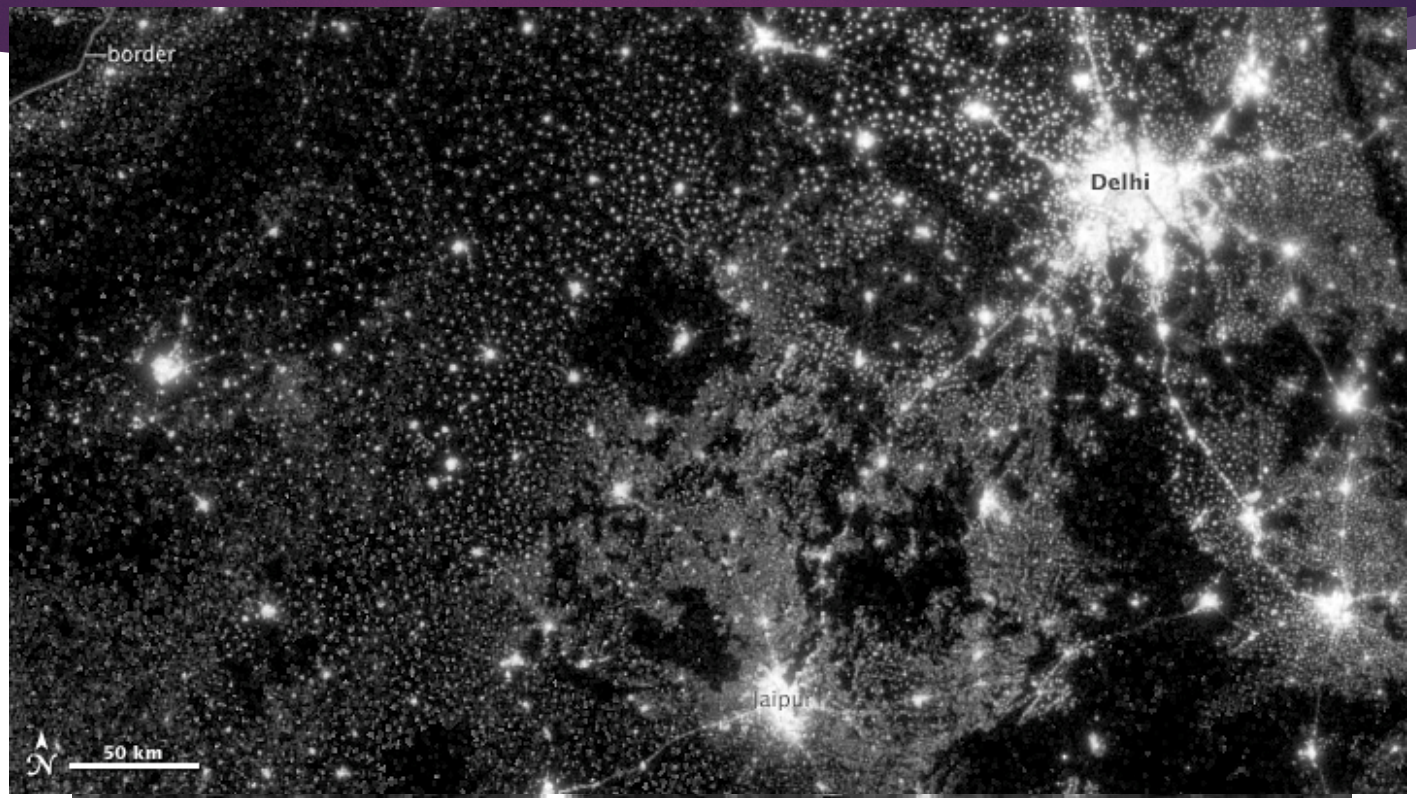
The Night Lights composite assembled from data acquired by the Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite over nine days in April 2012 and thirteen days in October 2012.

Defense Meteorological Space Program
Operational Linescan System (OLS)
Non-NASA Mission: Dept. of Defense and NOAA

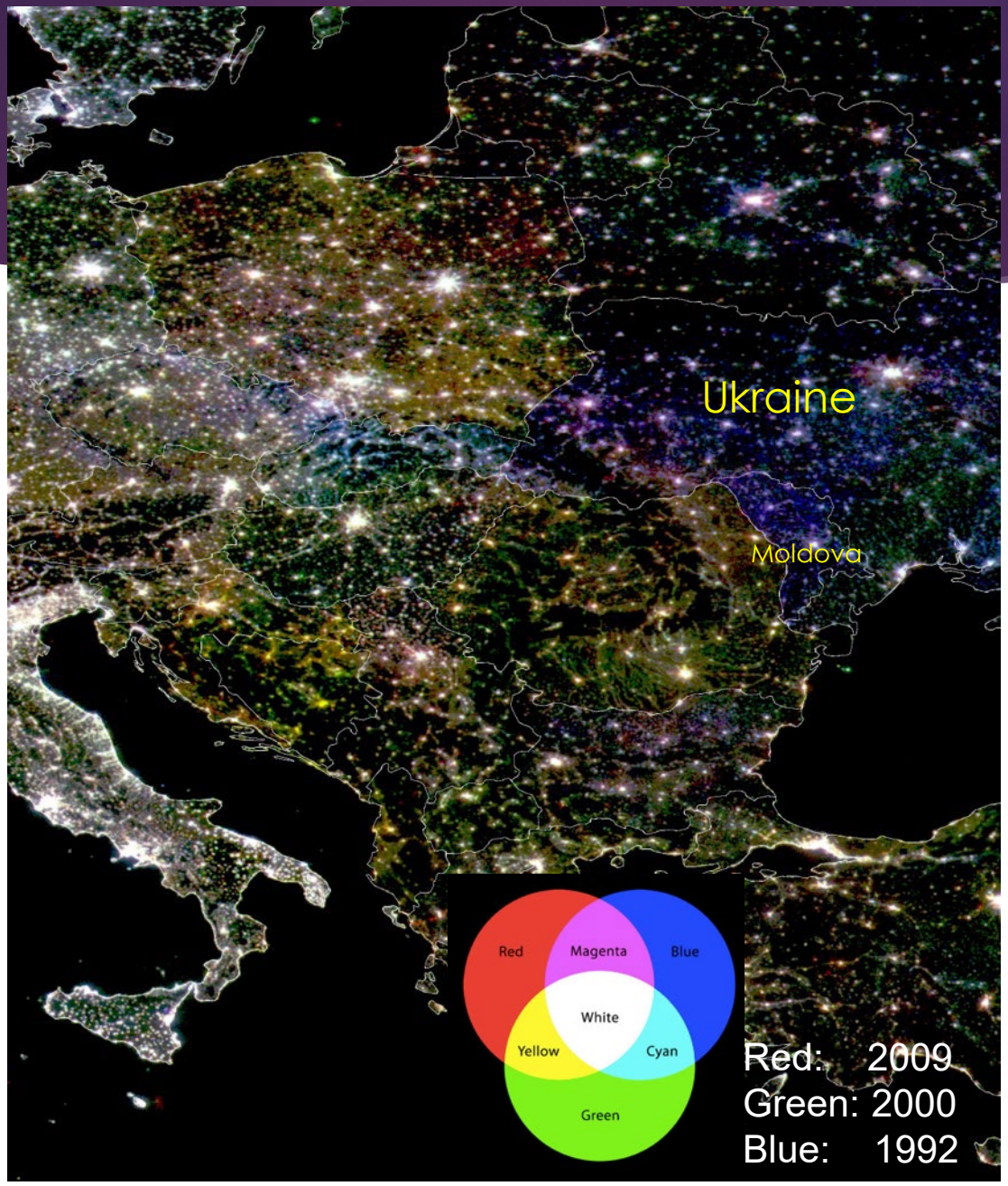
Original Time series: from1992 to 2013 New time series: 2012-2018



NPP/VIIRS versus DMSP/OLS: Delhi, India



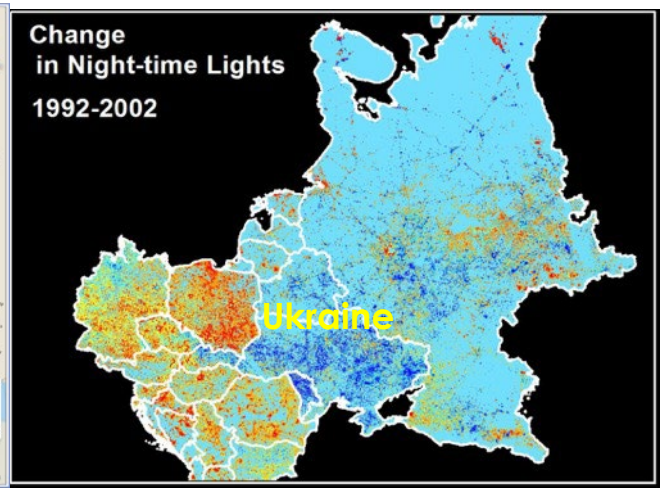
From OLS (5km^2/ 6 bits) → VIIRS(742 m^2 /14 bit)


Ukraine
Moldova
Red
Magenta
Blue
White
Yellow
Cyan
Green
Red: 2009
Green: 2000
Blue: 1992

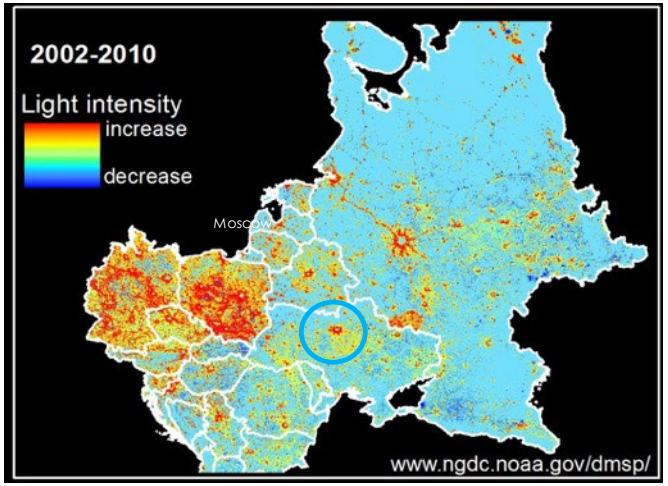
DMSP Night Lights Reflecting Changes in Economy

The Decade of Collapse

The Decade of Recovery



Deep Blue: Depressed Economies
(e.g. Ukraine & Moldova)
Red: Positive Economy Development

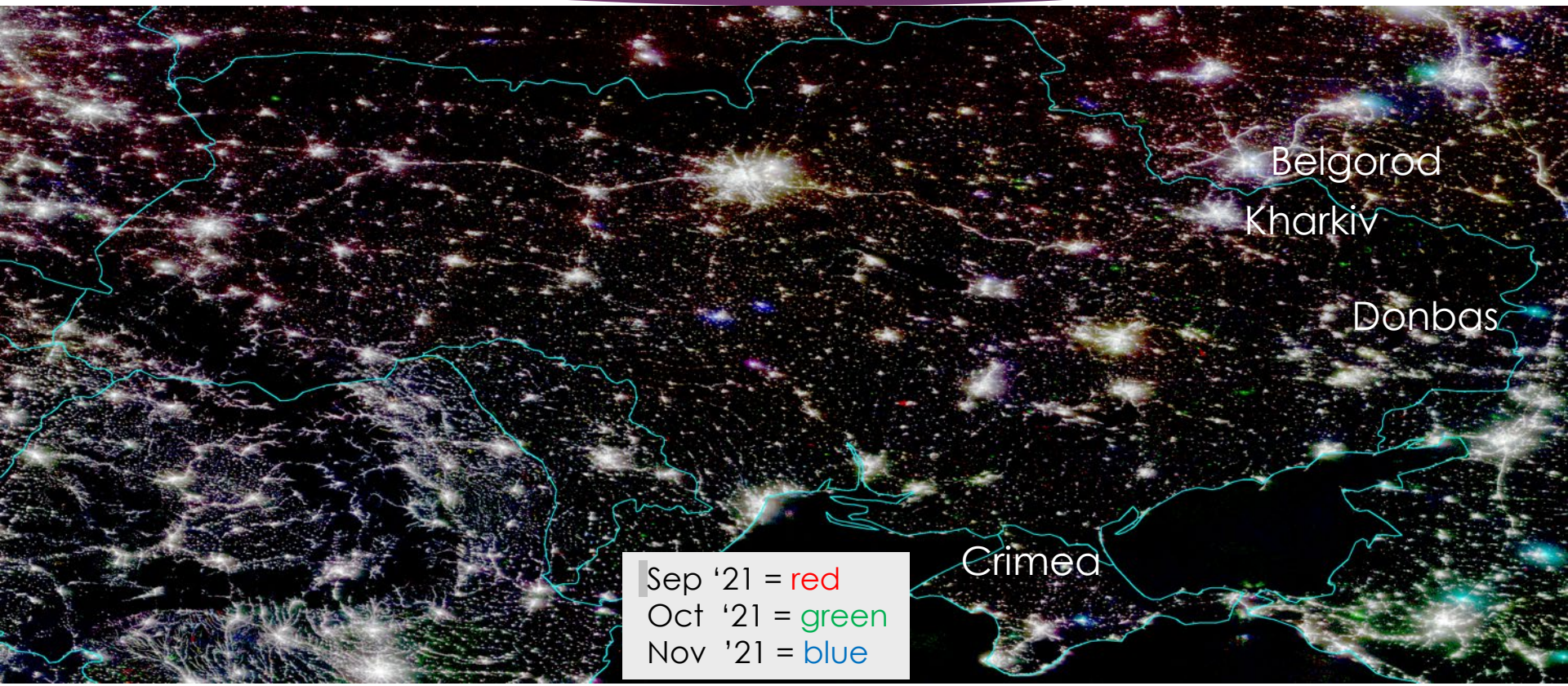


Light Blue: neutral (not much change)

Red: Economy and urban expansion

Courtesy: Chris Elvidge (School of Mines, formerly at NOAA)
Volker Radeloff (U. Wisconsin)

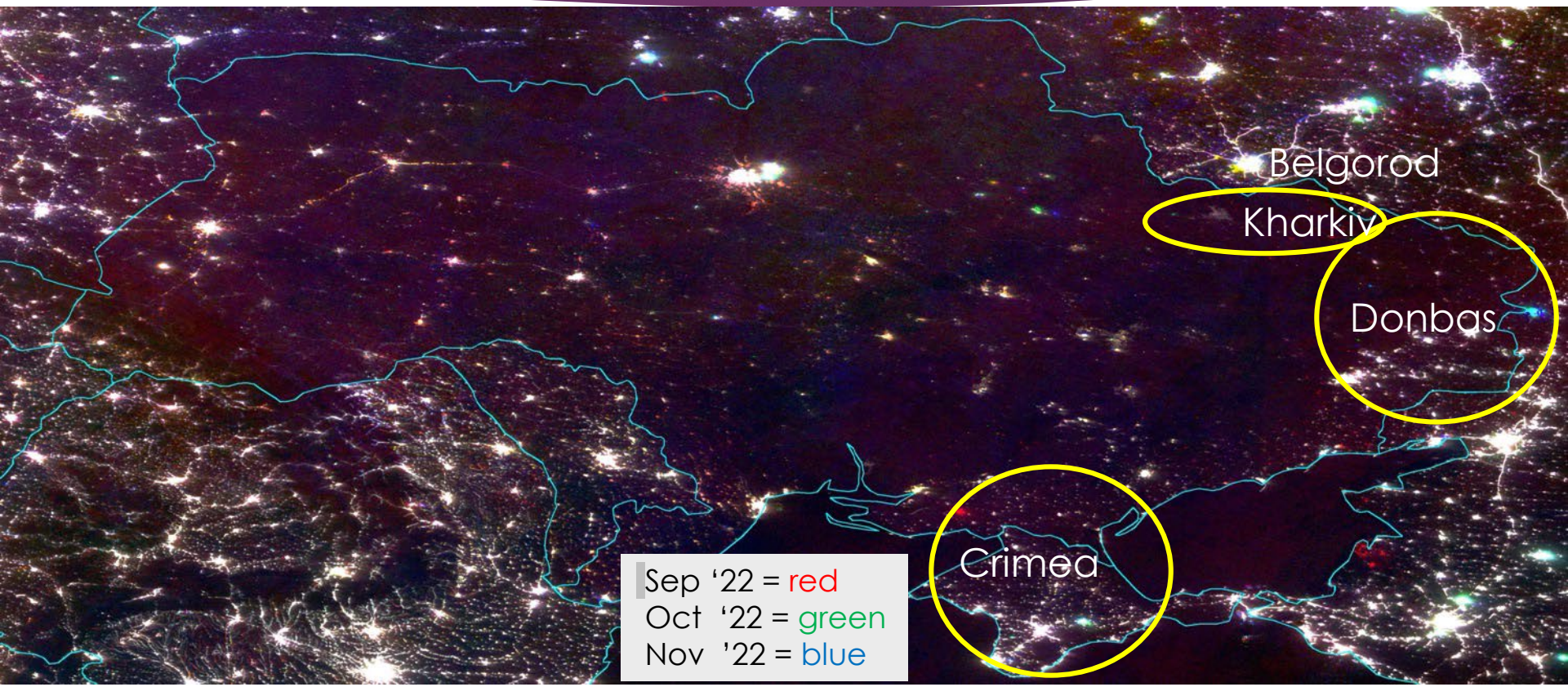
2021 Pre-war Condition: Ukraine



2021 VIIRS nighttime lights red-green-blue composite: Sep = red, Oct = green, Nov = blue. The white tones indicate the brightness of lighting is near equal in all three months.

Courtesy: Chris Elvidge (School of Mining)

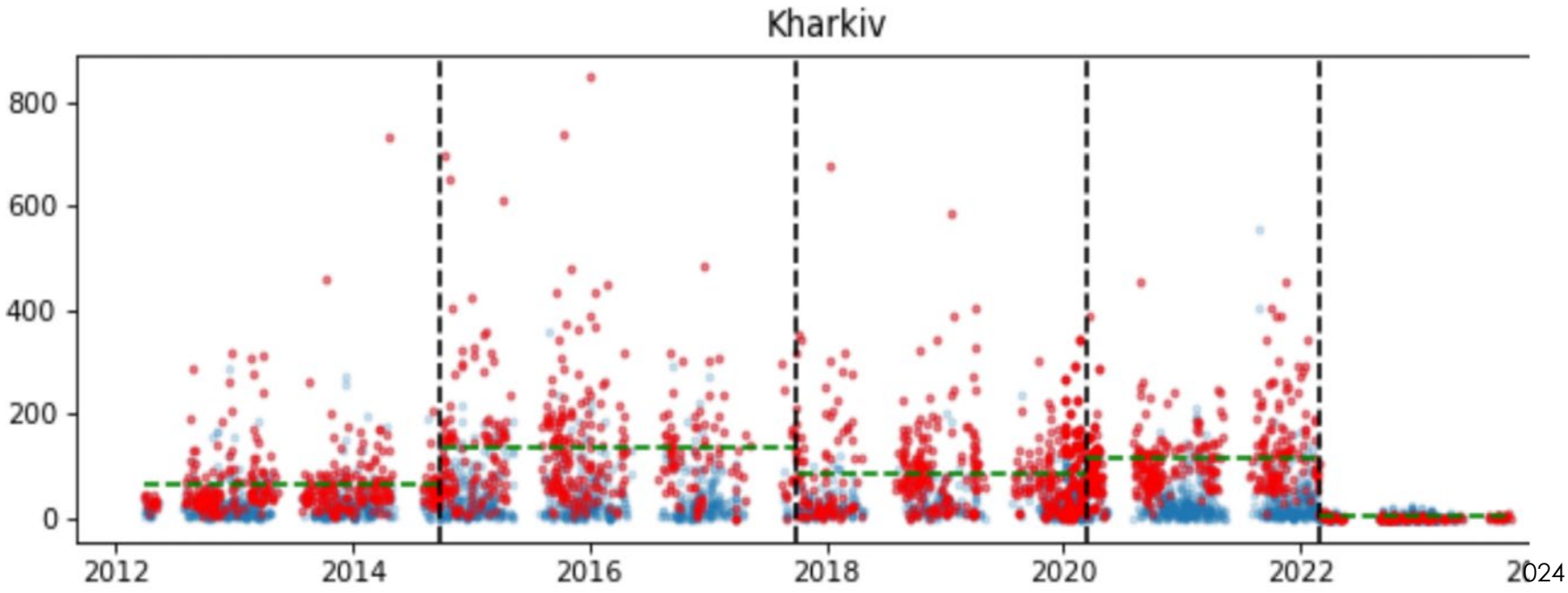
2022 War Impacted Condition



2022 VIIRS nighttime lights red-green-blue composite: Sep = red, Oct = green, Nov = blue. The white tones indicate the brightness of lighting is near equal in all three months in Russia-controlled areas.

Courtesy: Chris Elvidge (School of Mining)

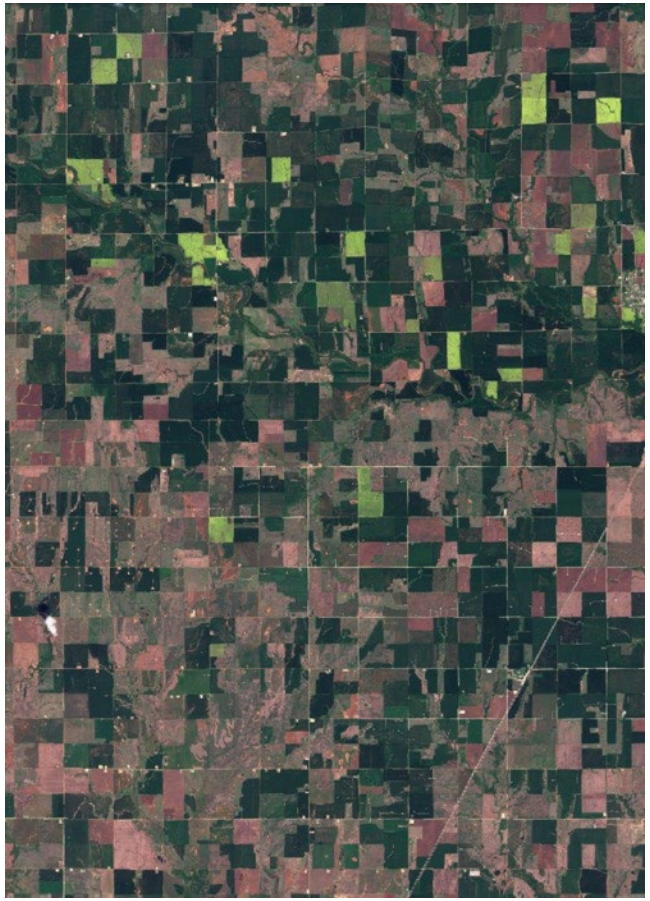
Kharkiv's VIIRS Nighttime Lights Through Years



red dots – clear
Blue dots - cloudy

Courtesy: Chris Elvidge (School of Mining)

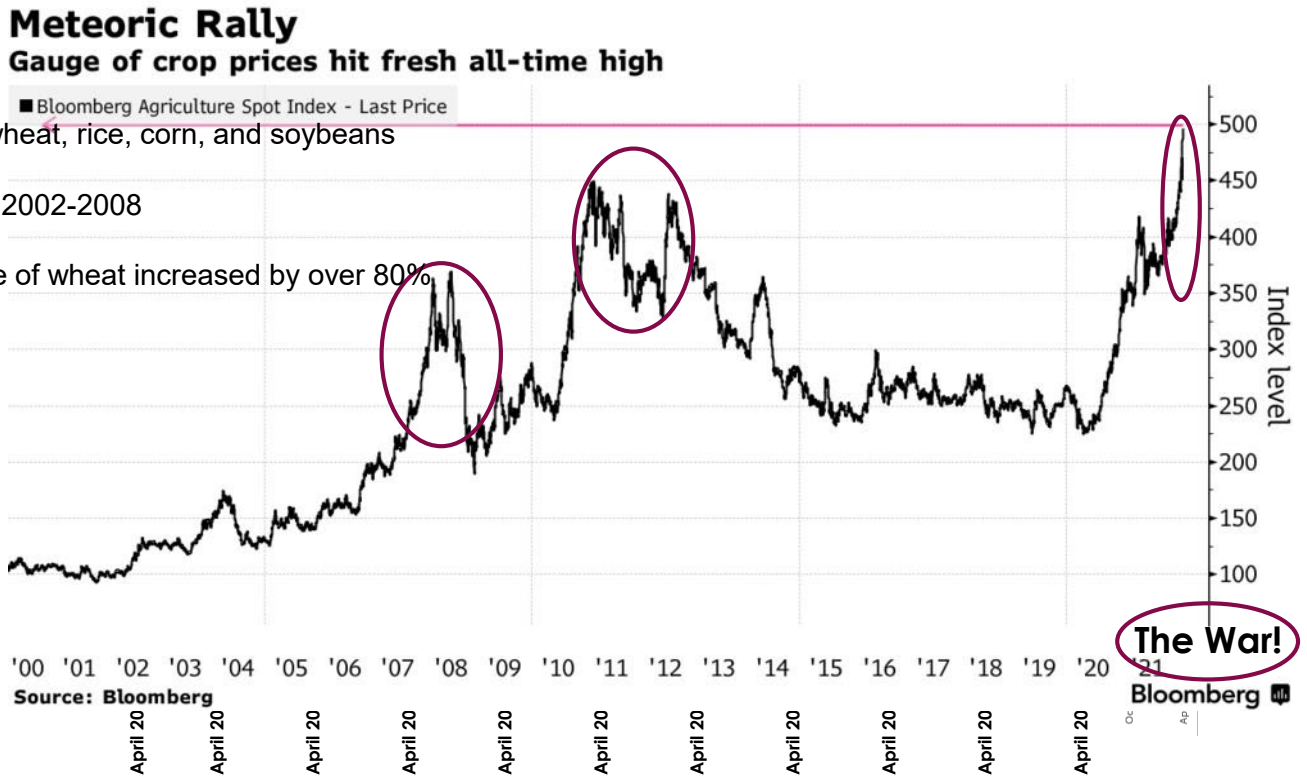
A New Era for Agricultural Monitoring From Space



- Satellite data offer **cost-effective**, **timely**, **transparent** information on
  - **crop type**
  - **plant health**
  - **stress**
  - **productivity** at the field to global scales on a nearly daily basis
- Major recent advances in **data**, **cloud & super computers**, and **big data analytics**

Why do we Need Agricultural Monitoring?

- World prices of wheat, rice, corn, and soybeans rose 226% from 2002-2008
- 2010 - 2011 price of wheat increased by over 80%

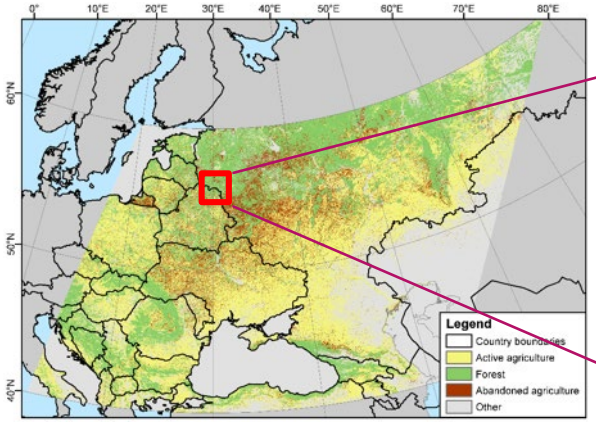


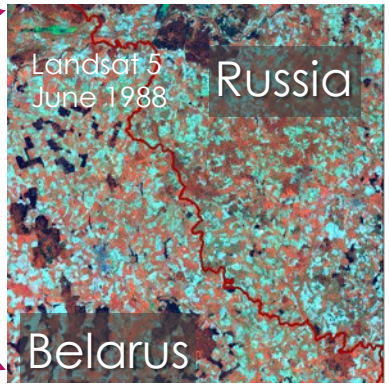
- The price increase pushed an additional 44 million people into poverty (FAO)
- 2011 Horn of Africa drought left over 13 million in need of food aid (FAO)

Land-Use Change After the Collapse of the USSR: Agricultural Abandonment

MODIS-derived abandoned agricultural areas in 2005

35 to 50 million hectares of croplands and grasslands managed in 1990 were abandoned by 2010





- Widespread agricultural land abandonment after the collapse caused by the socioeconomic shock that the collapse of the USSR represented
- Strong differences in abandonment rates among neighboring countries were caused by differences in policies and institutions

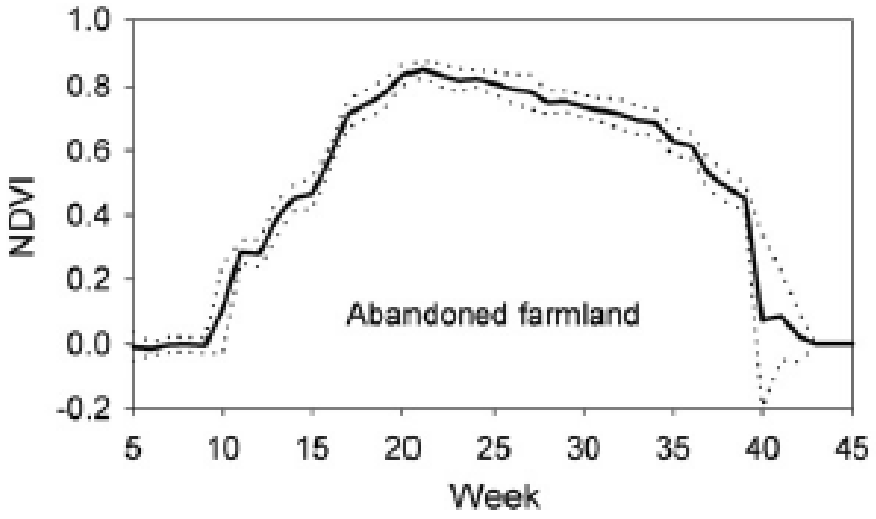
Notice the contrast on the two sides of the border between Russia (abandoned fields) and Belorus (managed fields)

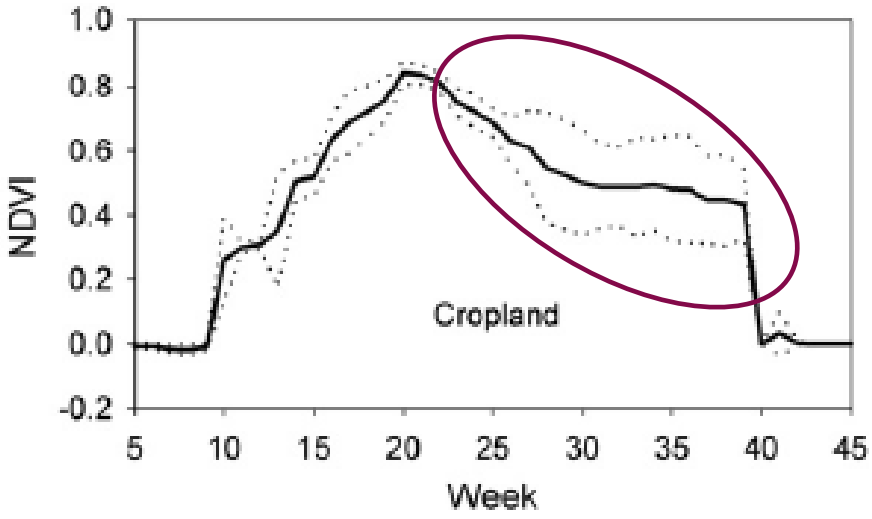
Land Abandonment →Overgrowing

Source: Gutman (field trip in northern Estonia in 2010)

Source of pictures: Prishchepov

MODIS-Derived NDVI Profiles for Managed and Abandoned Fields



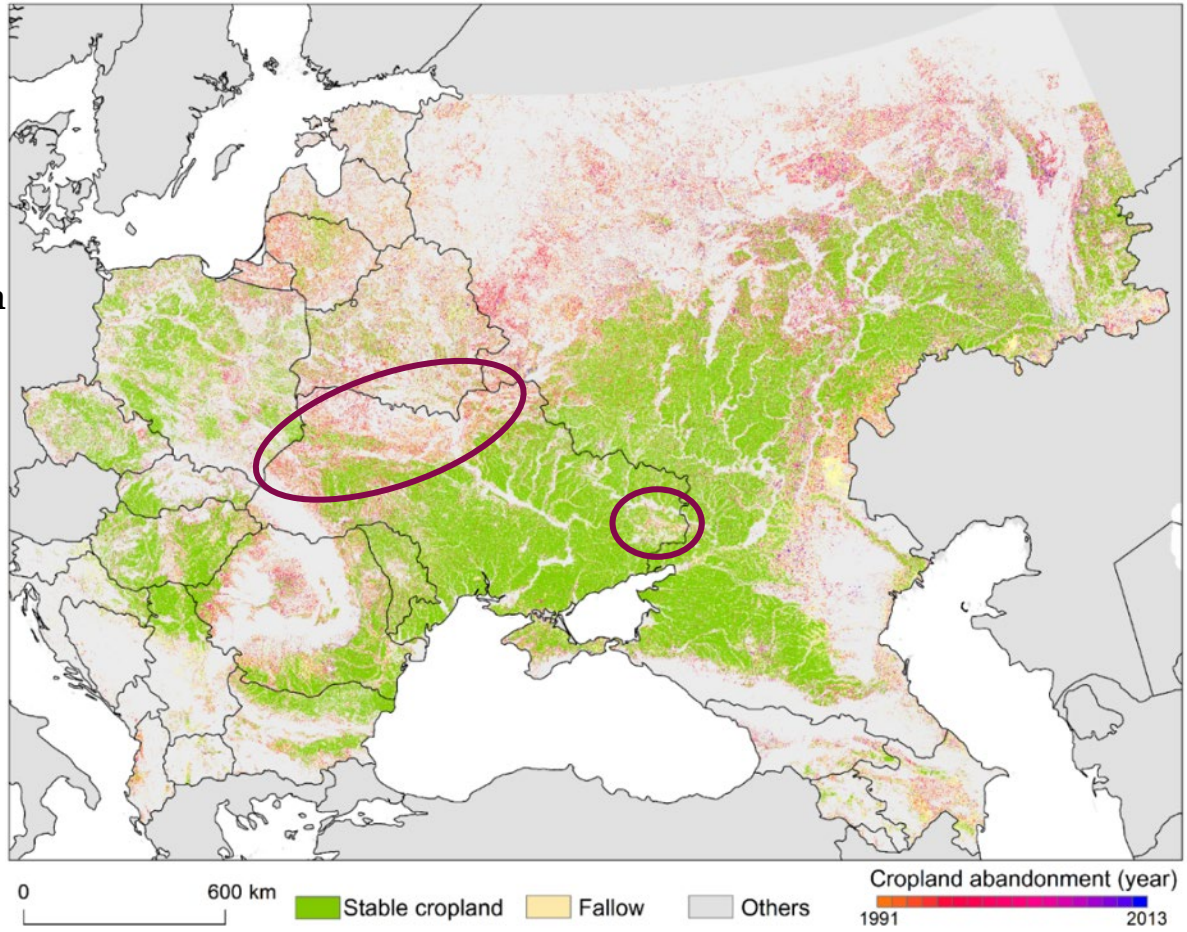


Phenology (time-series) metrics help to accurately distinguish managed and abandoned fields. Different integrals (areas under the curves) indicate the difference between the managed and abandoned fields.

Variability in the greenness on abandoned fields is much lower compared to actively cultivated fields (see Min & Max indicated by dotted curves).

Mapping Ag Abandonment With Landsat and Sentinel-2 Data

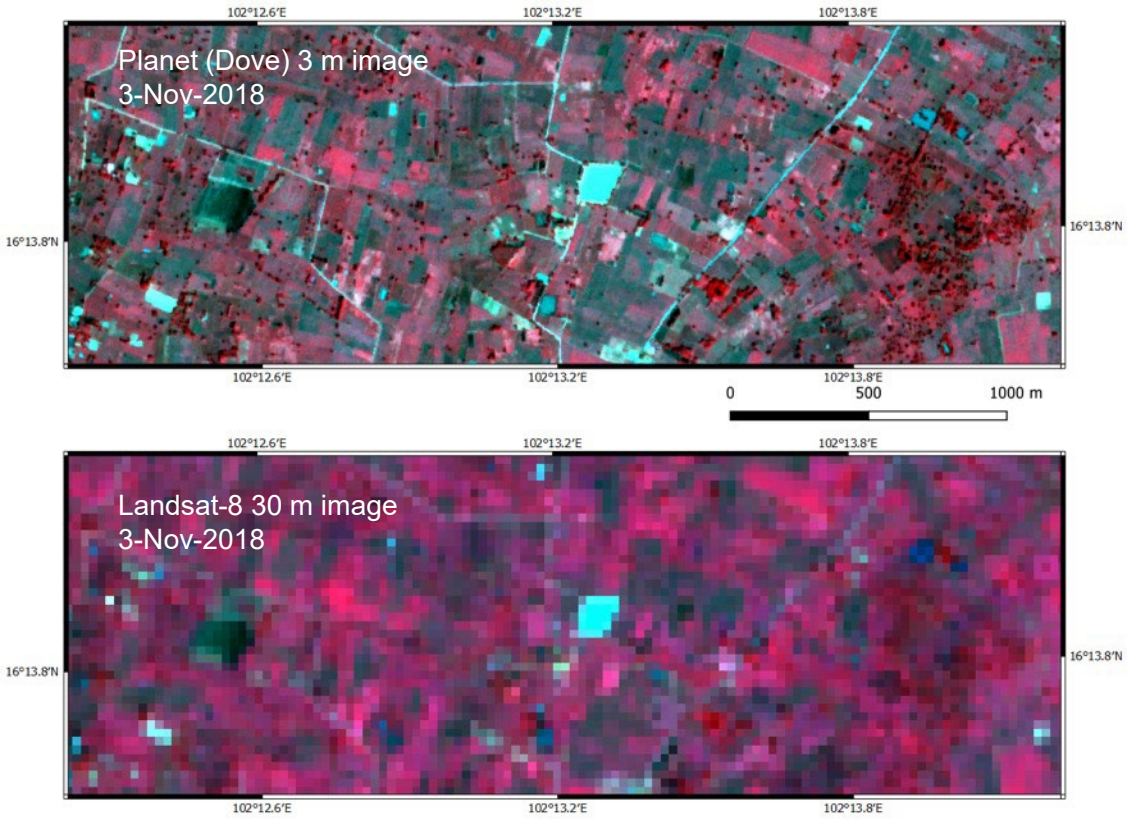
Annual abandonment, fallow fields, and re-cultivation at 30-m resolution across Eastern Europe. In the South, re-cultivation was common, in the North, abandonment was permanent.



Credit: V. Radeloff, U. Wisconsin

Effect of Spatial Resolution on Field Boundaries

Credit: Sergii Skakun (U. Maryland)

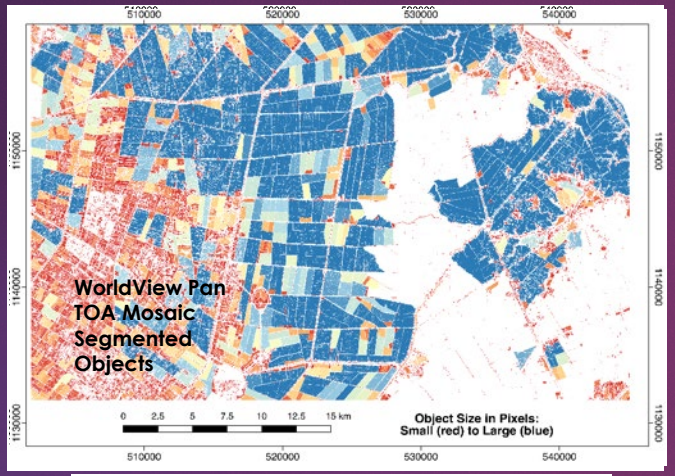


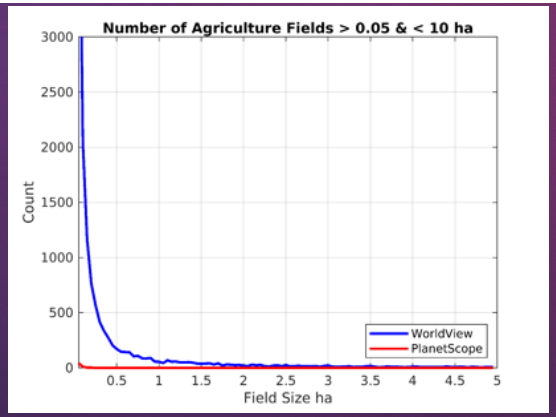
Agricultural fields (mostly sugarcane) in the Chaiyaphum province, Thailand

The small agricultural fields in Thailand can only be resolved with VHR data

VHR for Agriculture Land-Use Change Studies in the Mekong River Delta

PI: Jessica McCarty (Miami University, Ohio)





Study Areas:

I. Vietnam, Mekong River Delta
II. Đồng Tháp Province and Long Xuyên, An Giang Province

- Digital Globe WorldView 1-m data ability to discriminate small fields as compared to 3-m Planet Dove data
- Field boundaries **have to be resolved near the sub meter scale** to segment individual fields into distinct objects

- Derived objects are more robust when combined with Sentinel-1 SAR to estimate cropping intensity
- Due to persistent clouds the temporal advantage of PlanetScope is severely limited for mapping cropping intensity

Using Very High-Resolution Data: Commercial Satellite Constellations

Planet Labs

- **PlanetScope** (>200 sats) acquire daily images of the Earth with 3-m res.
- **SkySat** 15 sat constellation, 50-cm res
- **Pelican** 32 sat const., 30 cm res, SAR
- **RapidEye** 5 sats, 5-m res.

Maxar Thechnologies
meter and sub-meter res.

WorldView Legion 6 sats

- 30 cm res. multispectral optical imager (can be pan-sharpened to 15 cm).
- Up to 15 revisits per day

January Fires in LA Area

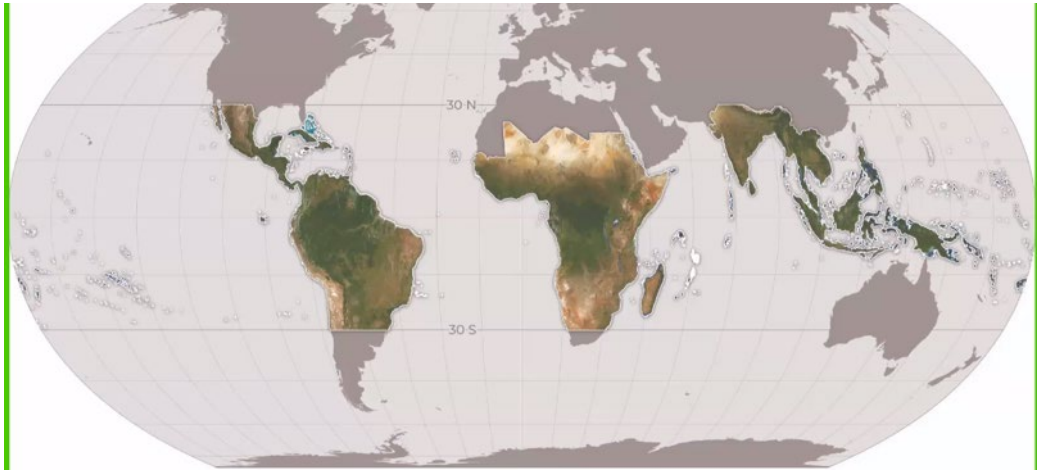
MAXAR Image of East Altadena Drive in Altadena, CA.

VHR Data Availability

- NASA Commercial Smallsat Data Acquisition (CSDA)
- Limited Planet datasets are available for free at Universities
- Wall-to-wall VHR data over tropics purchased by the government of Norway (to tackle tropical deforestation)

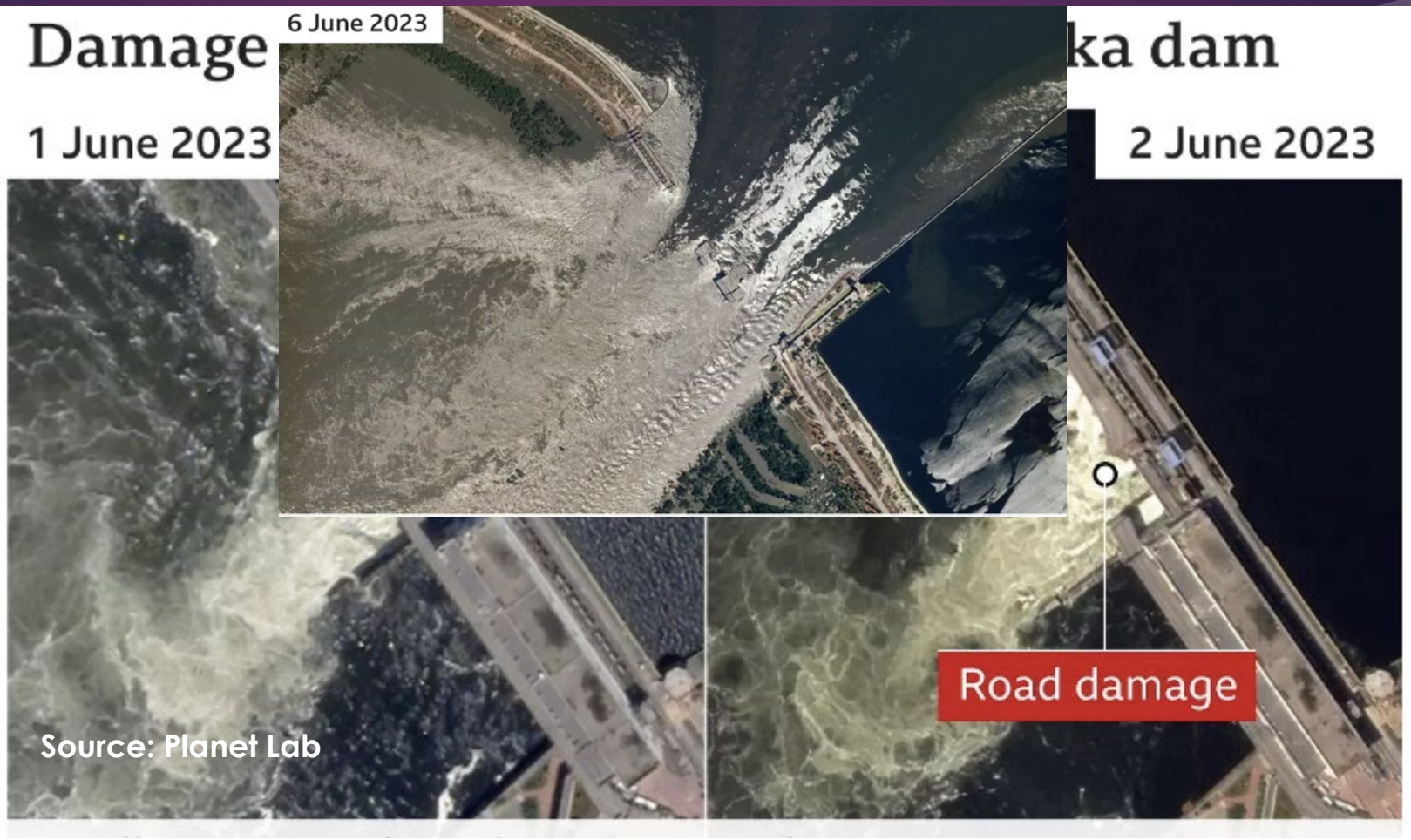
- Norway's International Climate and Forest Initiative (NICFI) 30°N-30°S mosaics (<5m) based on **Planet data**
  - Monthly mosaics: Sep 2000- end of 2024
  - Bi-annual mosaics: Dec 2015 – Aug 2020
- Access: www.planet.com/nicfi

Global Forest Watch Project
https://www.globalforestwatch.org



Bezos Earth Fund in partnership with NICFI will continue providing the world with free access to high-resolution satellite data to support efforts to stop the destruction of the world's rainforests, protecting them, and enhancing monitoring.

Kakhovka Dam Damage as Observed With Planet Data



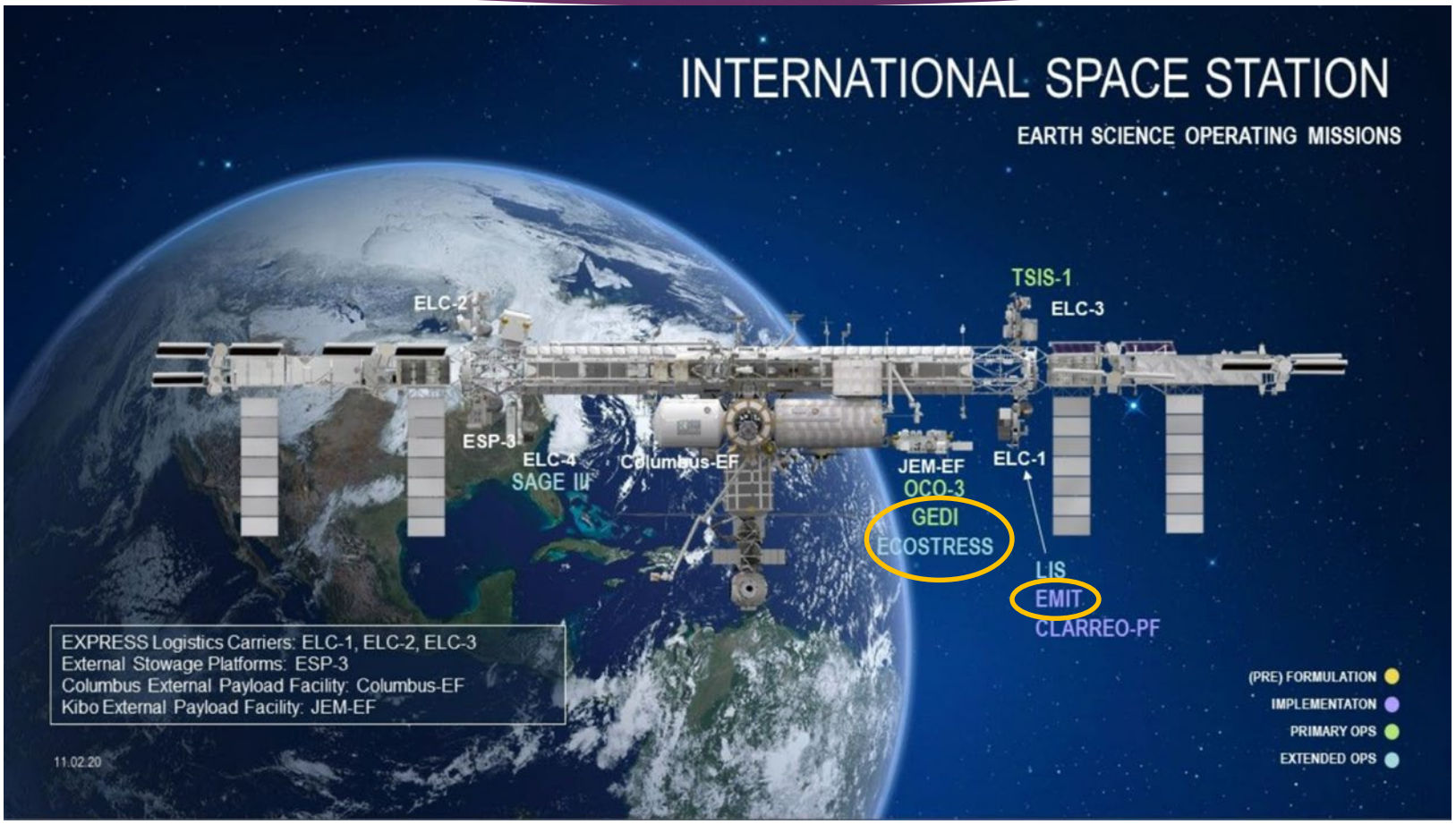
Flooded streets in Kherson

Kherson Flood as Observed With Planet 3-m Data

Kherson District Flood: as Observed With Maxar Data

Large-Scale Assessment of the Kakhovka Flood from SENTINEL-3 Thermal IR Images

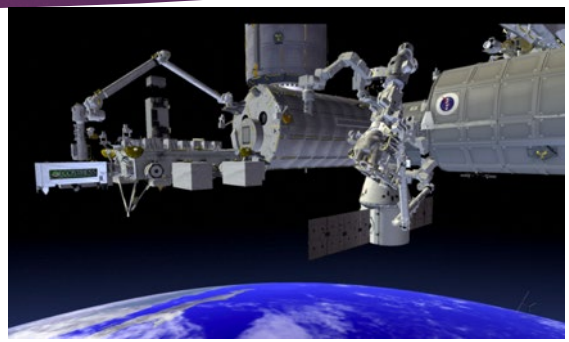
Using Instruments on ISS for LCLUC Studies

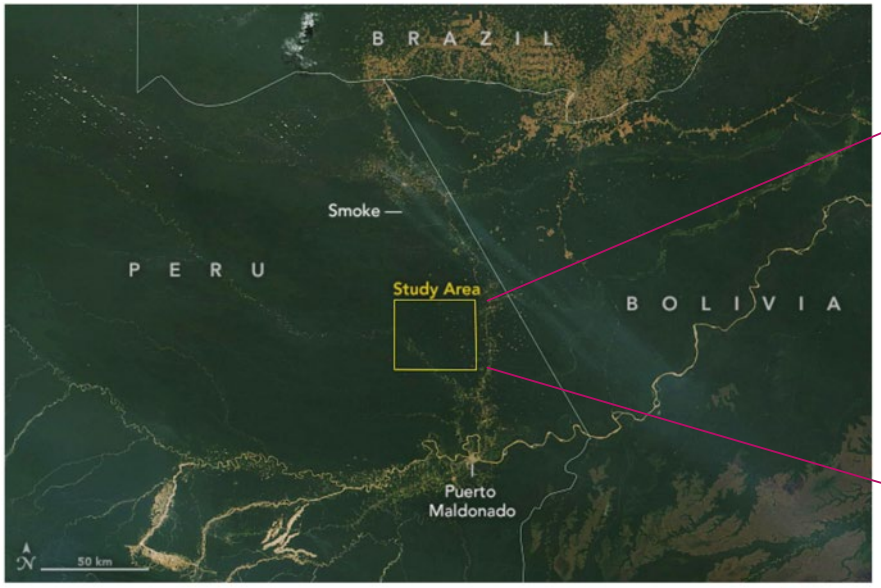


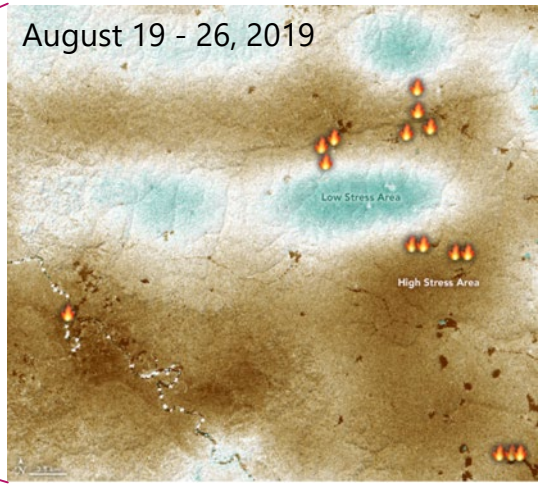
ECOSTRESS: NASA Instrument on ISS

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

- Launched June 29, **2018**
- 5 infrared bands in the 8-12.5 µm range +1.6 µm
- Spatial resolution ~70 m







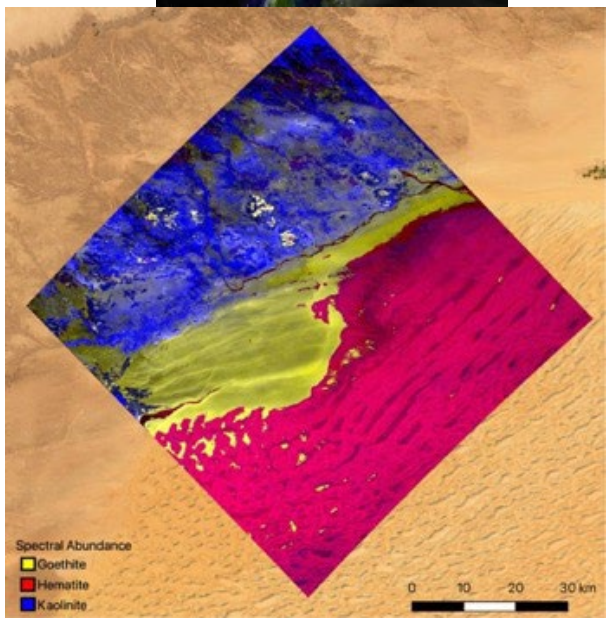
MODIS fire detections
(August 19 - 26)

Evaporative Stress
Low
High

MODIS: August 18, 2019

EMIT on ISS
Earth Surface Mineral Dust Source Investigation

- Launched in July 2022
- Advanced imaging spectrometer with spectral range: 380-2500 nm
- **Primary applications: mineral dust, its heating and cooling effects in the atmosphere**
- **Potential other applications**
  - **natural hazards (** flood extent, ecosystem impacts, and surface water sediment load)
  - **environmental pollution (**oil spills, ocean plastics, acid mine drainage, etc.)
  - **coastal waters and harmful algal blooms (**ocean phytoplankton, harmful algal bloom biomass and composition, coral presence and bleaching events, and the health of coastal ecosystems)

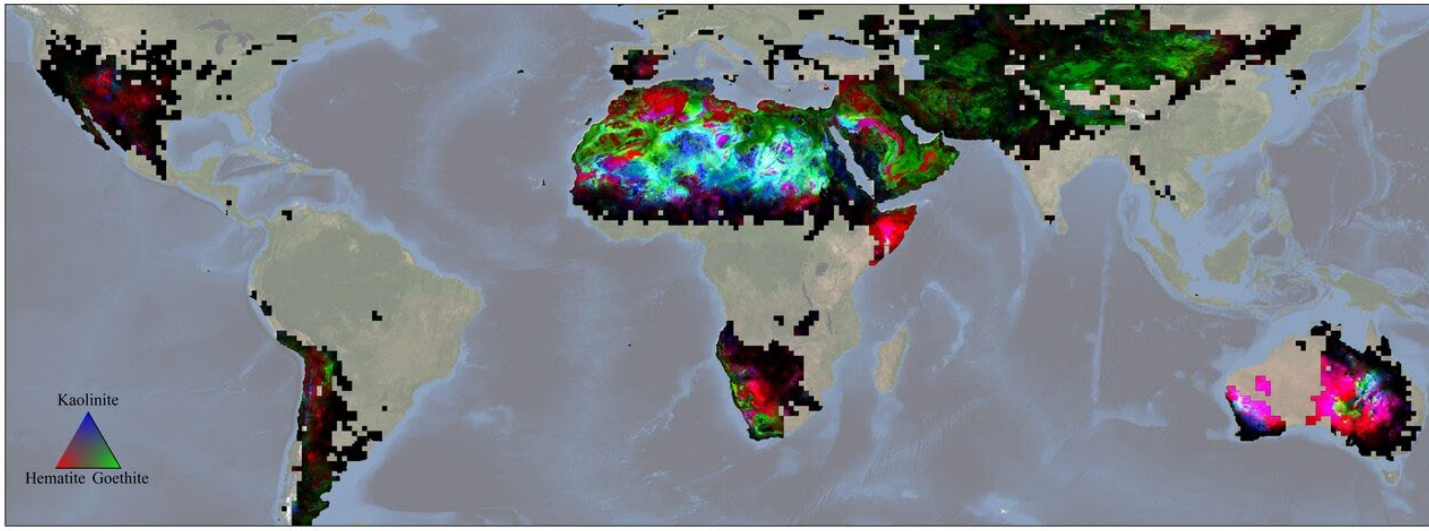


Credit: JPL

EMIT first light: The mineral map in southwestern Libya in the Sahara Desert

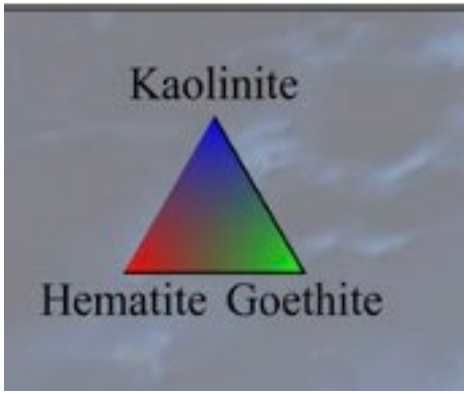
EMIT: First Global Map of Mineral Composition in Arid Regions

Kaolinite is a soft, earthy, usually white, mineral (“china clay”),used for manufacturing ceramics, porcelain ware and floor or wall tiles. The name is based on the name of the village of Gaoling, China.

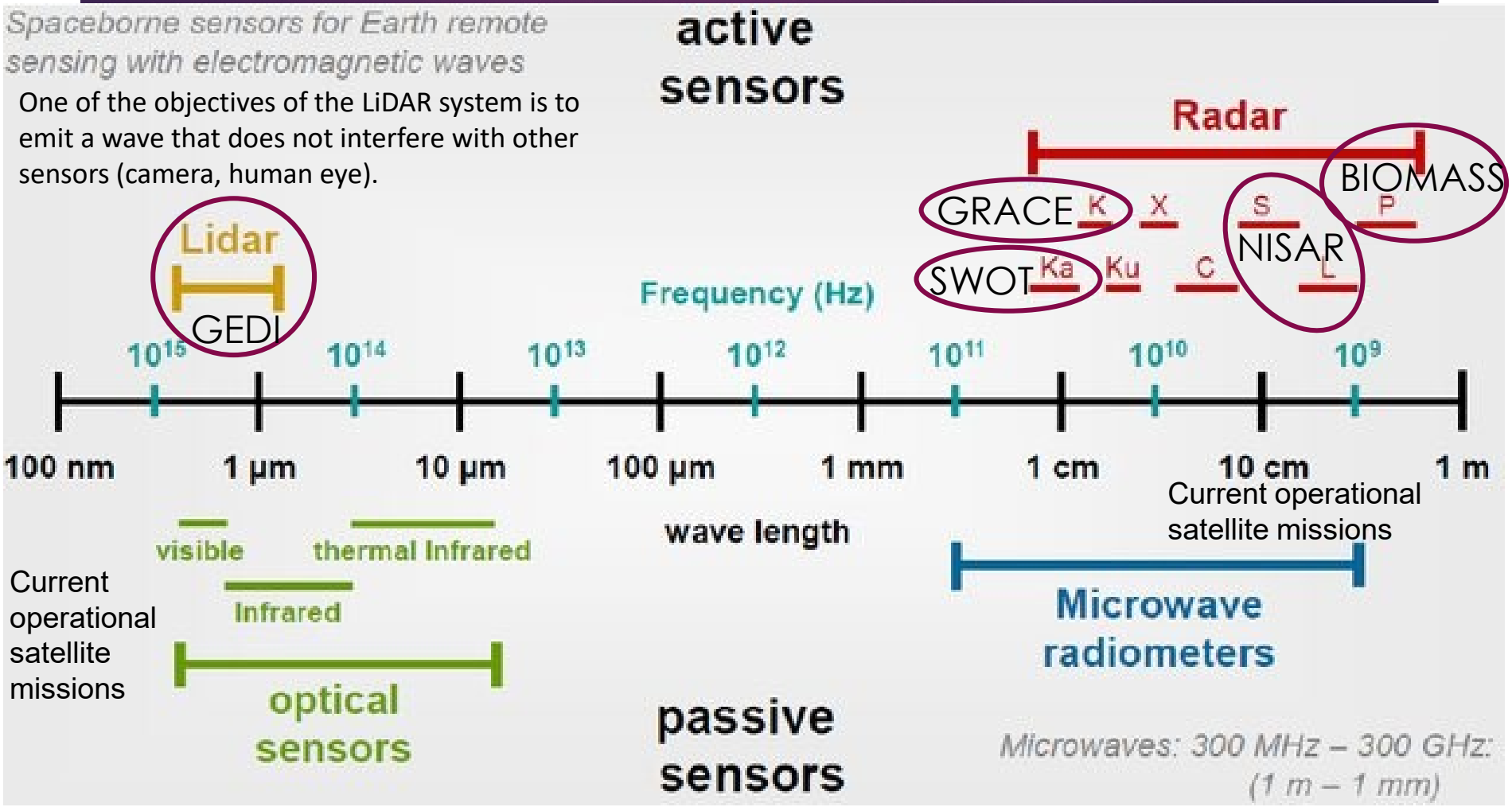


Hematite is an important mineral for iron ore, an oxide mineral found in red, orange and brown colours. Derived from the Greek word for blood, due to the red coloration, often used as a pigment.

Goethite is the main mineral in iron ore, which is used to make steel. Used a a pigment (brown ochre)The mineral was named after the poet Goethe.

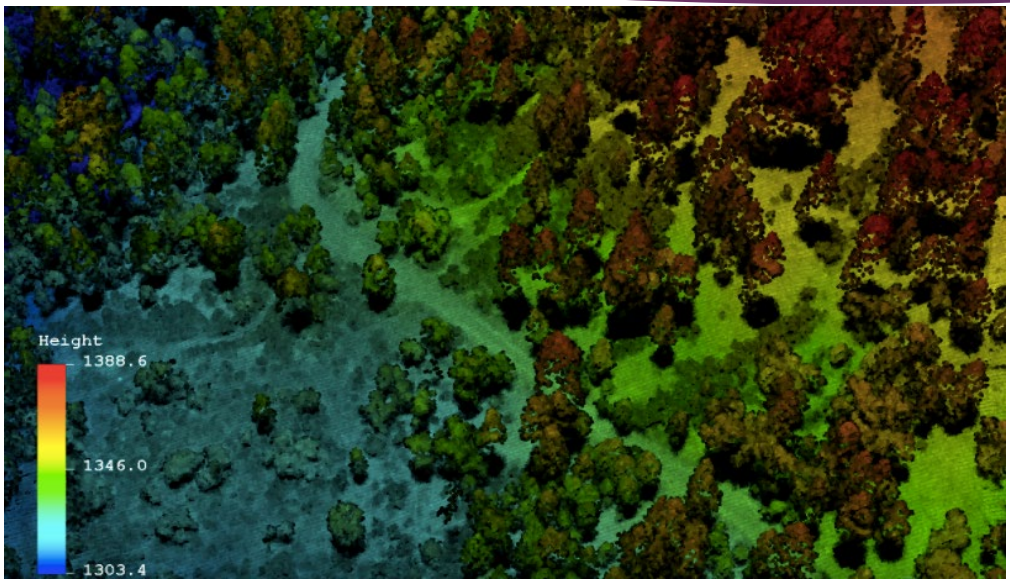


Active Remote Sensing

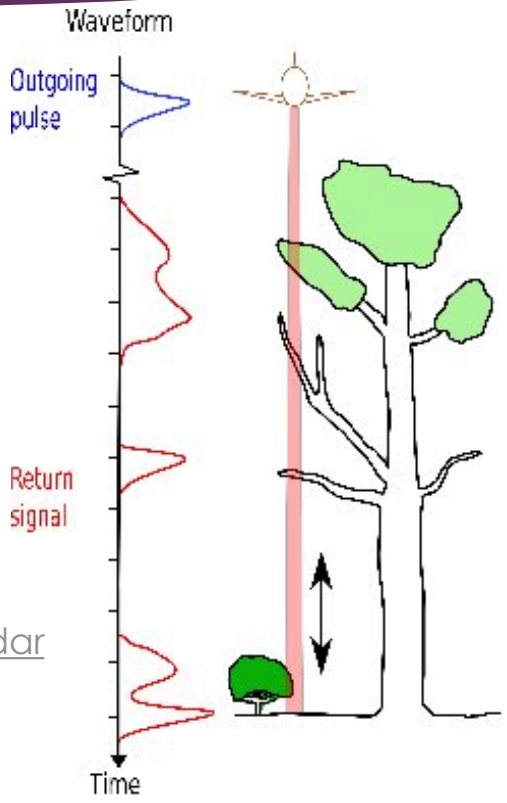


Passive Microwave radiometer records the natural **microwave** emission from the Earth
the **spatial resolution** of **passive microwave** observations is generally low **(SMOS 35-50km)**

Active Optical: Vegetation Height from Lidars



https://lidarradar.com/info/advantages-and-disadvantages-of-lidar



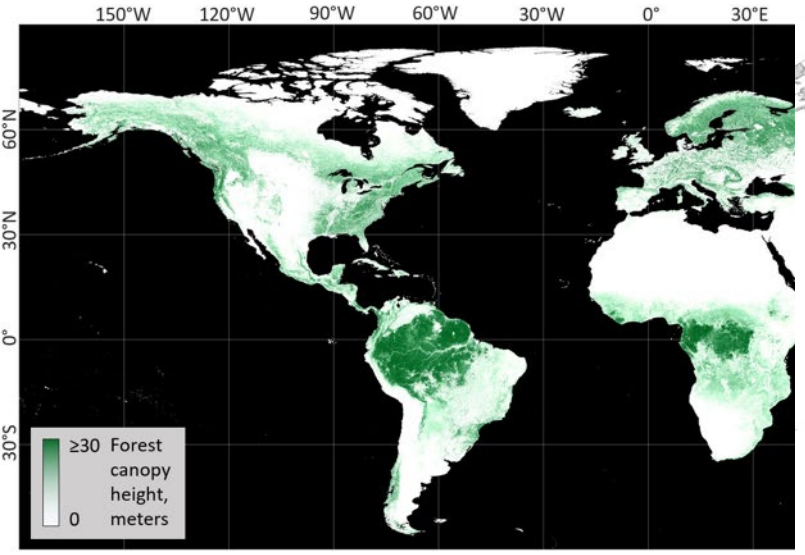
Source: Chauve et al. 2008

Global Ecosystem Dynamics Investigation
NASA GEDI Instrument on ISS

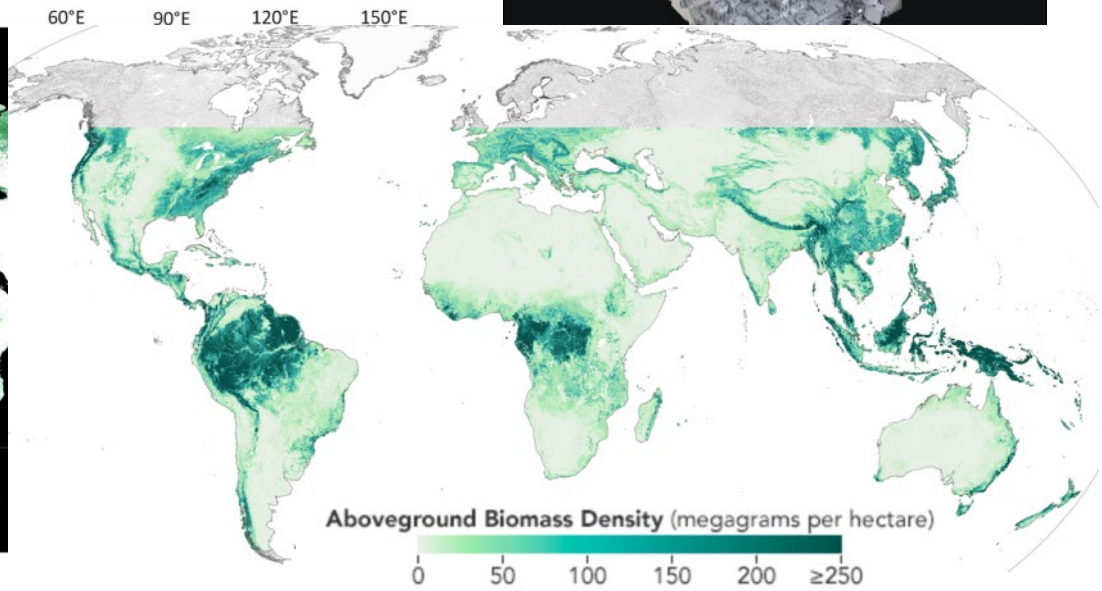
- High resolution laser ranging observations
  - Launched June 29, 2018
  - three lasers produce eight parallel tracks of observations

Global Land Analysis & Discovery

Integration of the GEDI lidar forest structure measurements and Landsat analysis-ready data time-series



Global Forest Canopy Height: 2019

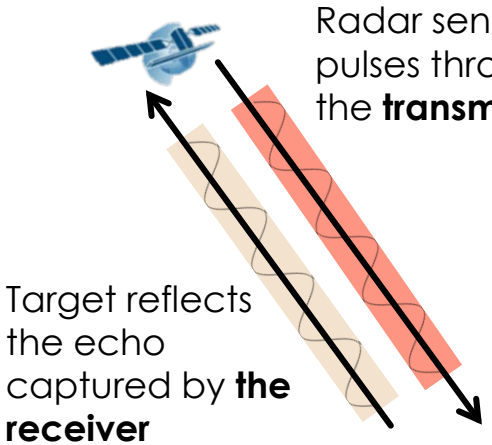


April 18, 2019 - August 4, 2021

Active Microwave: Radar Principle

RADAR: ***R***adio ***D***etection ***a***nd ***R***anging

- Active system (generates, transmits and captures signal)
- Relatively high spatial resolution (same as optical)
- Day-night & all-weather capabilities
- Complementary to optical systems



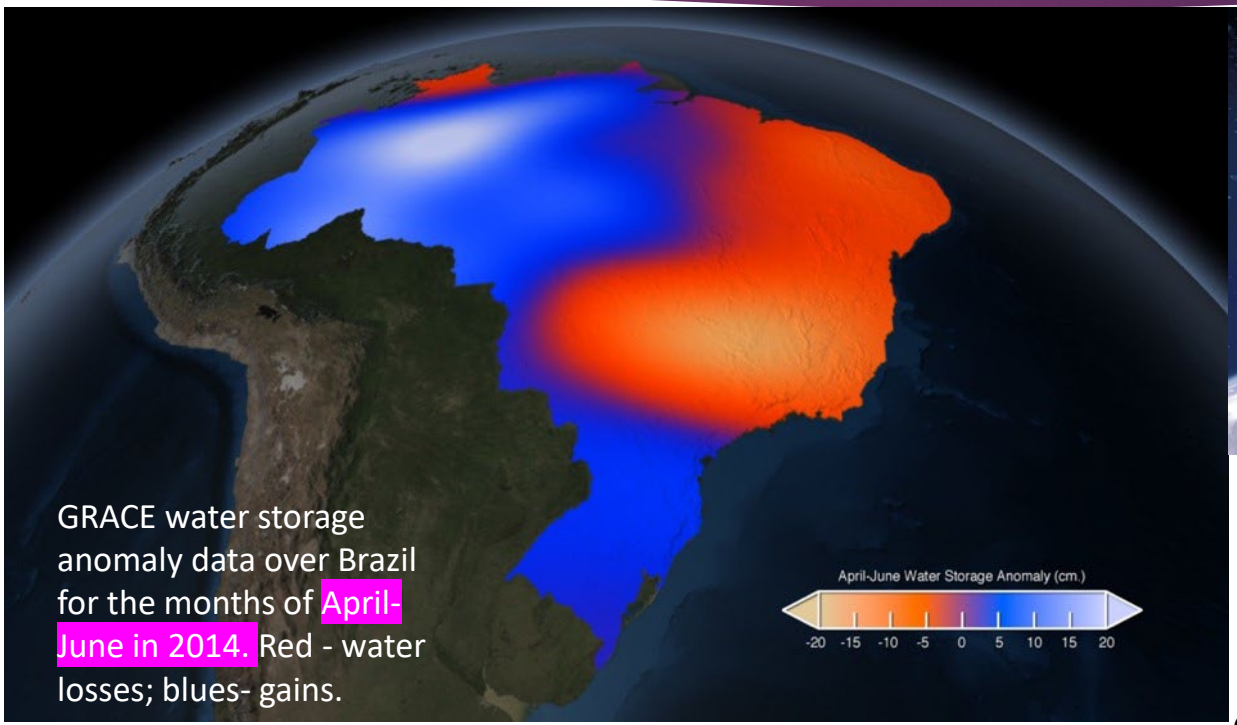
NASA-CNES Surface Water and Ocean Topography (SWOT)

- SWOT's 120-km-wide swath with overlaps over most of the globe with an average revisit time of 11 days
- Launched Dec 16, **2022**
- On land, it will collect data on lakes and reservoirs larger than 62,500 m^2 and rivers wider 100 m with 50-m spatial and 10-cm height resolutions
- All weather - penetrate cloud cover and the dark of night

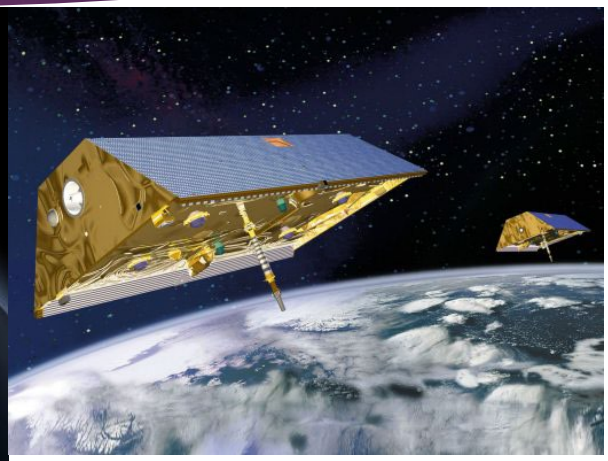
SWOT will survey nearly all water on Earth's surface for the first time with **Ka-band Radar** Interferometer (KaRIn, frequency between 26.5 and 40 GHz)

NASA's GRACE Satellites

The joint US/German GRACE (Gravity Recovery and Climate Experiment)



GRACE water storage anomaly data over Brazil for the months of April-June in 2014. Red - water losses; blues- gains.



NASA GRACE satellites, launched in 2002, deorbited in 2018,
The follow-up mission launched Grace-FO

- Microwave **K-band ranging** instrument

GRACE measured changes in the local pull of gravity as water shifts around Earth due to changing seasons, weather and climate processes.

http://www.nasa.gov/feature/goddard/nasas-grace-satellites-evaluate-drought-in-southeast-brazil

Future Grace-C is planned for **2028**

Near-Future NASA Missions

- NASA-ISRO SAR (NISAR) Mission (2025)
- Surface Biology and Geology (SBG) Mission (2028-2029)
- Landsat Next (2031)

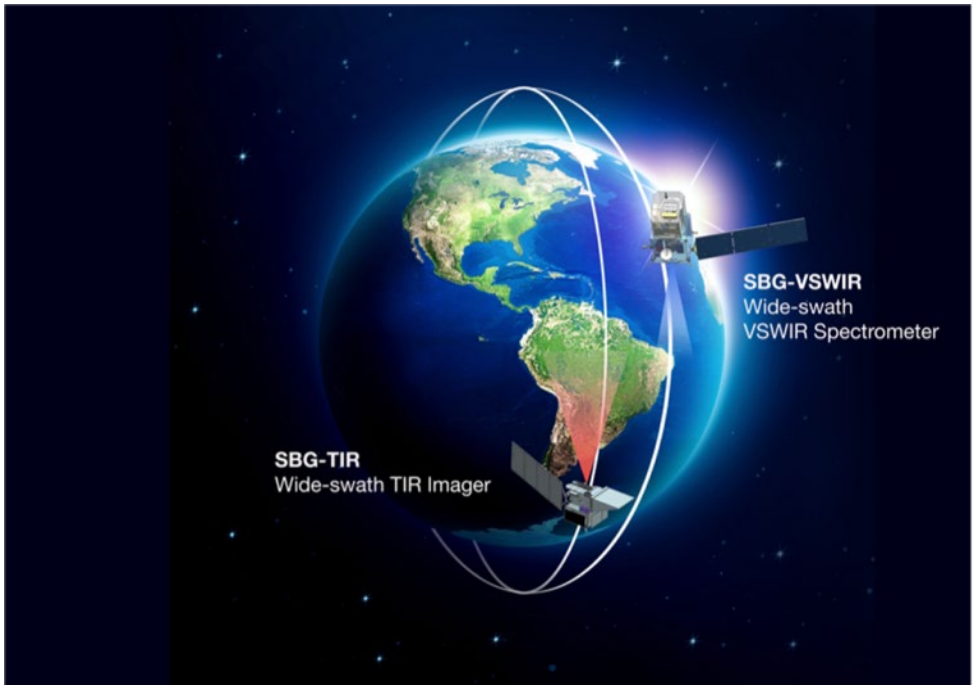
NASA-ISRO SAR (NISAR)

- Will observe Earth's land and ice-covered surfaces globally with 12-day repeat cycle
- Swath of 242 km
- Resolution 3–48 m for L-band
- Resolution of 3-24 m for S-band
- Planned Launch Date: March-April **2025**
- Will observe the distribution of vegetation and biomass to better understand ecosystems' responses to disturbance and recovery
- Will map above-ground woody biomass density for estimating carbon emissions from land-use change with much more accuracy

L-band (24 cm) and S-band (12 cm) **polarimetric SAR**

Future NASA-ASI Surface Biology and Geology (SBG) Mission

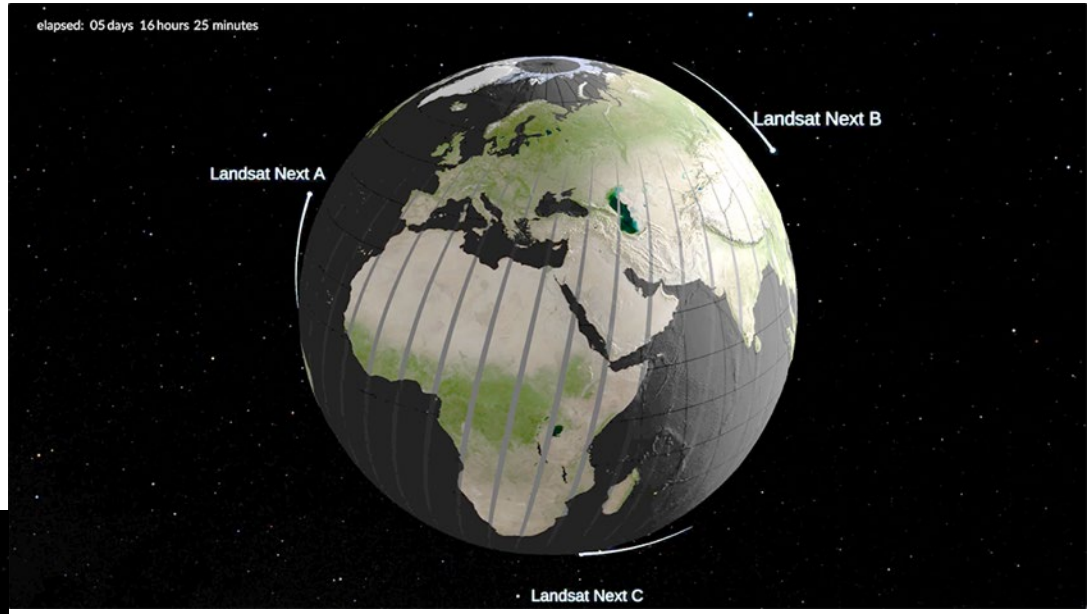
- **ASI- Agenzia Spaziale Italiana**
- SBG VSWIR will collect hyperspectral visible to shortwave infrared only during the day over both ocean and land
  - Spatial resolution 30 meters
  - planned to launch in March **2029**
- SBG-TIR will collect during the day and at night thermal IR data over ocean and land
  - planned to launch in July **2028**
  - NASA/JPL: TIR Instrument
  - Italian Space Agency (ASI): Visible and Near-Infrared (VNIR) Camera
  - Spatial resolution VNIR 30 meters
  - Spatial resolution TIR 60 meters

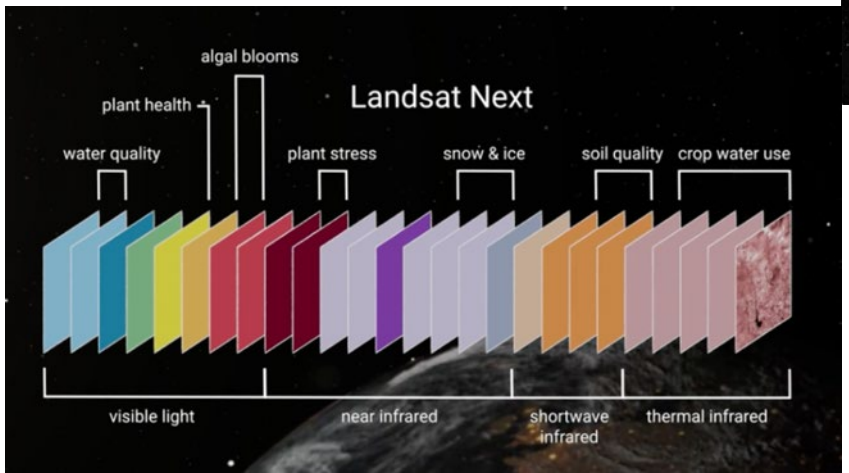


Future Landsat Mission: Landsat Next

- Constellation of 3 satellites
- 26 wavelengths bands
- More frequent and finer resolution
- Planned for Launch: **2031**

https://www.youtube.com/watch?v=axYgyzA68TI





Landsat Next constellation of three spacecraft will provide finer spatial resolution (10-20m) and expanded spectral (26 band) imaging capabilities every six days (at the equator)

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