Evaluating Ecosystem Services with Remote Sensing

Amber McCullum, Juan L. Torres-Pérez

Aug. 23, 2022

Course Structure and Materials

- Three, 1.5-hour sessions on August 23, 25, & 30 at 11:00-12:30 EDT (UTC-4) (English)
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-evaluating-ecosystem-services-remote-sensing
  - Q&A following each lecture and/or by email at:
    - amberjean.mccullum@nasa.gov or juan.l.torresperez@nasa.gov

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Answers must be submitted via Google Forms
  - **HW Deadline: Tuesday, September 13th**

- **Certificate of Completion:**
  - Attend all three live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately two months after the completion of the course from: marines.martins@ssaihq.com

Prerequisites

- Prerequisites:
  - Please complete Sessions 1 & 2A of Fundamentals of Remote Sensing or have equivalent experience.
- Course Materials:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-evaluating-ecosystem-services-remote-sensing

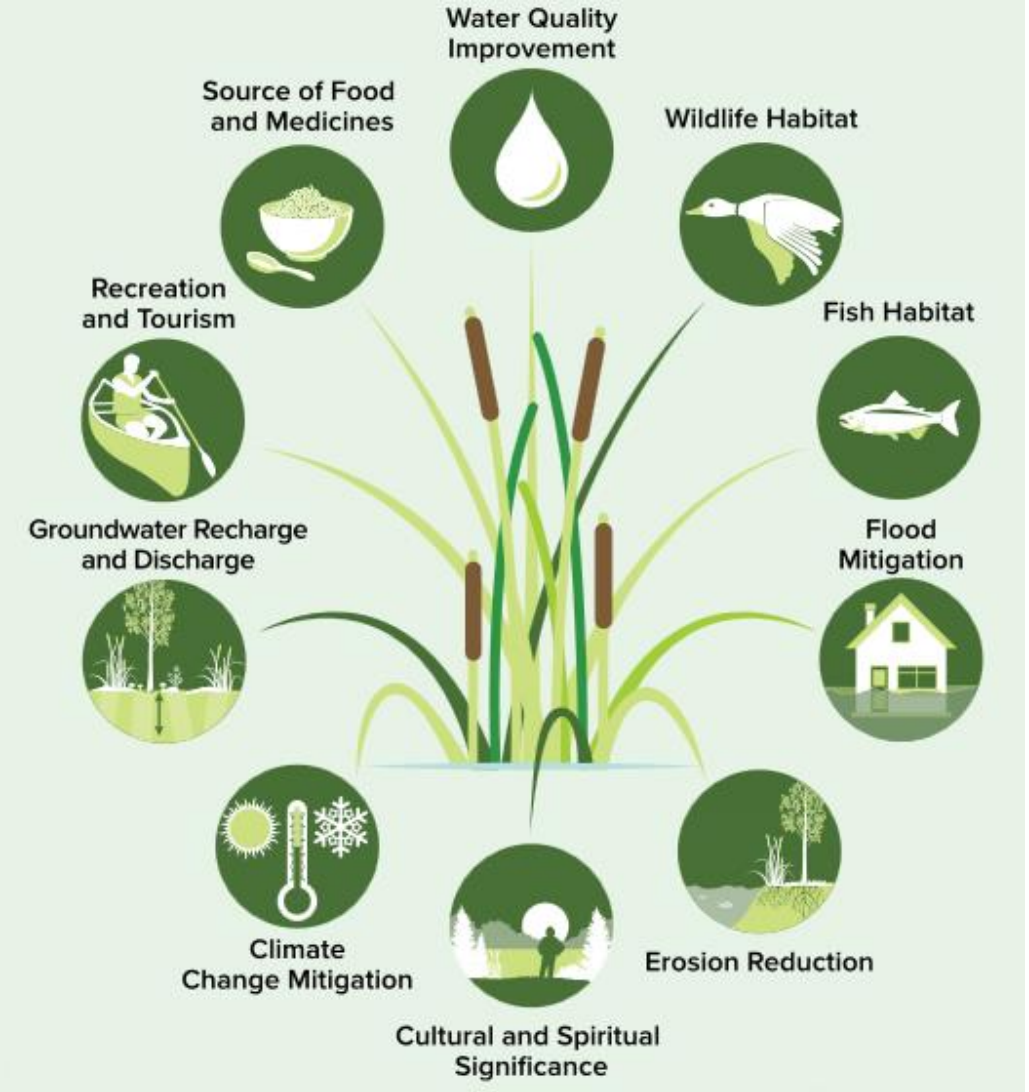
NASA's Applied Remote Sensing Training Program (ARSET)

- Part of NASA's Applied Sciences Program
- Empowering the global community through remote sensing training
- Seeks 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

Learning Objectives

By the end of this session, you will better understand:

- Ecosystem services
- Ecosystem service valuation
- Global frameworks and initiatives for assessing value of ecosystems
- The role of remotely sensed data and available products for ecosystems services



Ecosystem Services: Image Credit: Ontario Ministry of Natural Resources and Forestry. 2017.

Ecosystem Services Overview

What are Ecosystem Services?

- Ecosystem services are the benefits people obtain from ecosystems.
  - There is a wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life.

Image Credit: IWIM

Image Credit: Upsplash

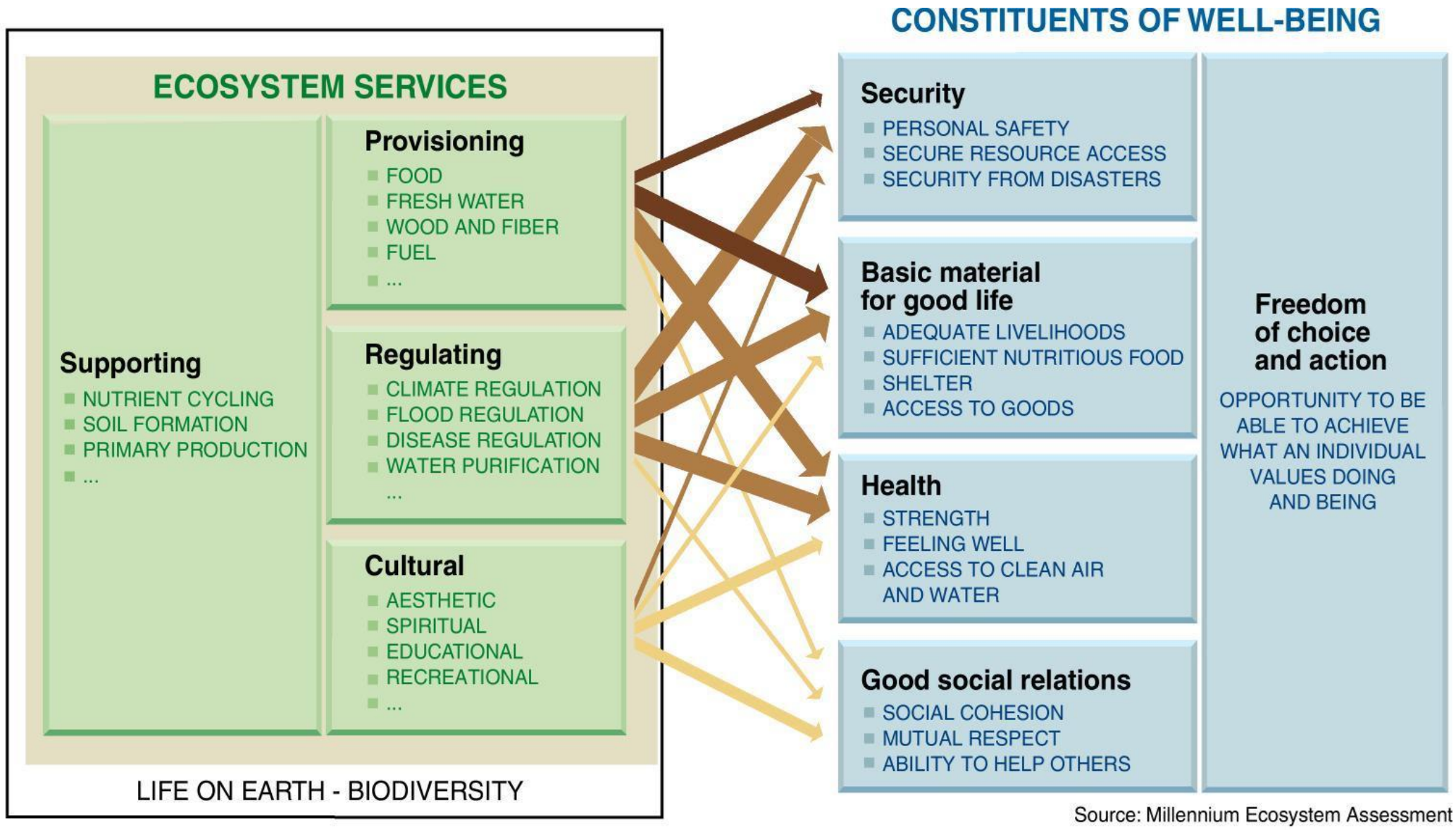
Image Credit: Science.com

What are the different types of ecosystem services?

- **Provisioning** (food, fresh water, timber, wood and fiber, genetic resources, medicines, etc.)
- **Cultural** (educational, aesthetic beauty, cultural heritage, recreation, spiritual and religious values, and tourism)
- **Regulating** (climate, air quality, water, disease regulation, pest control, and pollination)
- **Supporting** (processes necessary for proper functioning of other services, such as provision of habitat, primary production, soil formation, and nutrient cycling)

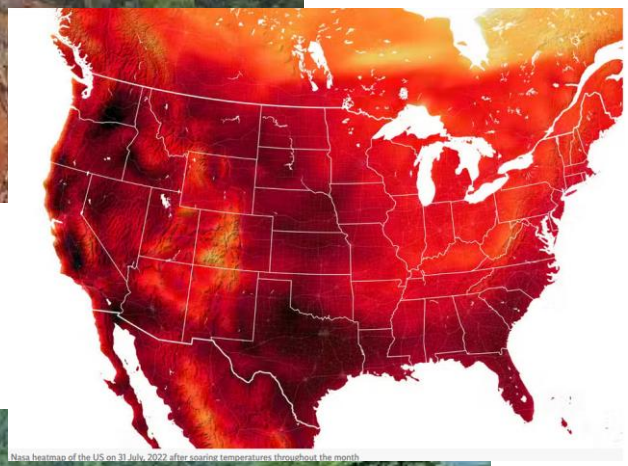
Image Credit: MEA

Ecosystem Services and Human Well Being

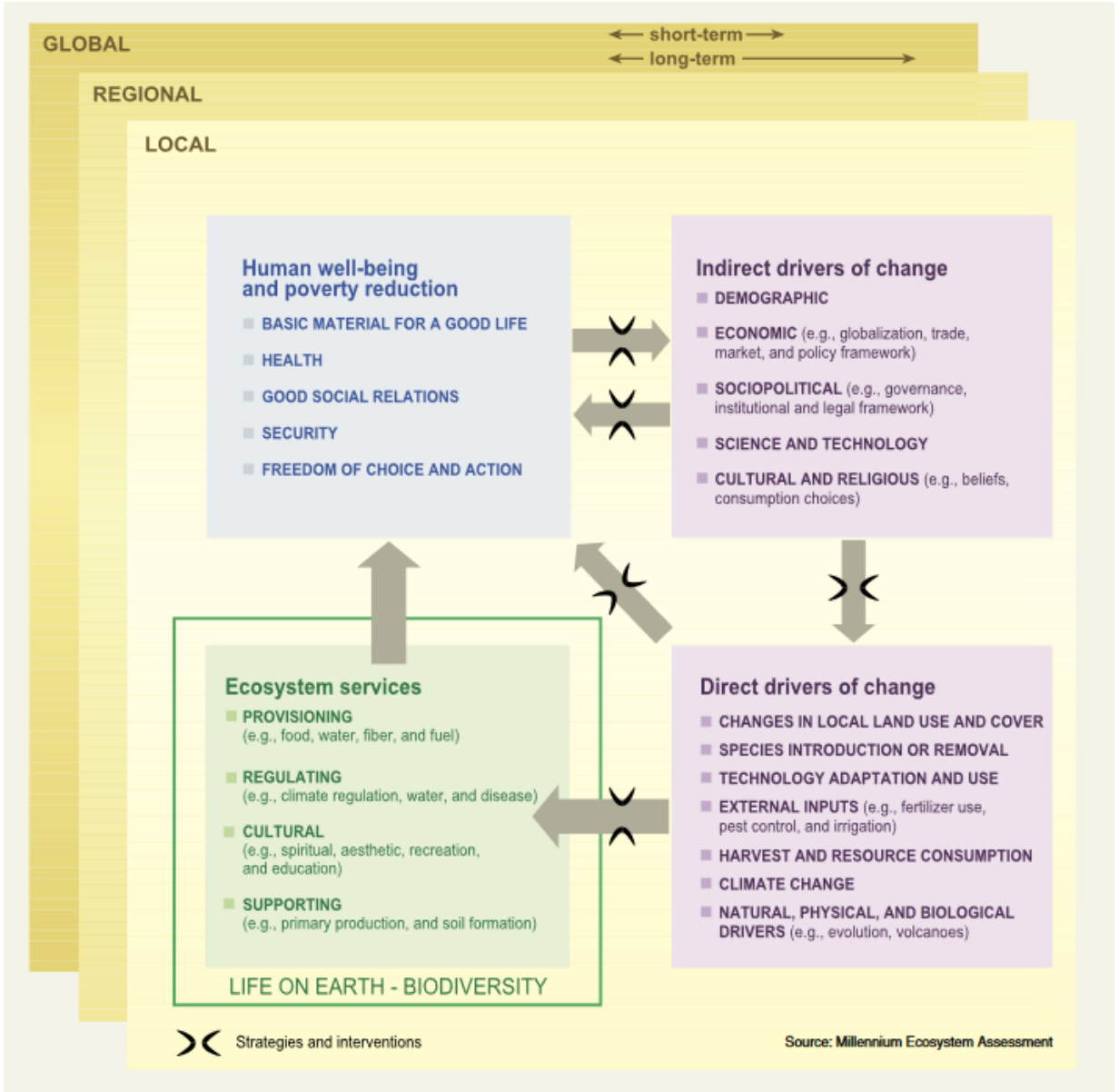


Source: Millennium Ecosystem Assessment

Ecosystem Services and Human Well Being



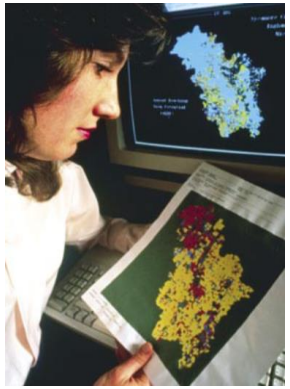
Nasa heatmap of the US on 31 July, 2022 after soaring temperatures throughout the month



Millennium Ecosystem Assessment 2005

- Assessed the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being.
- Four international conventions:
  - Convention on Biological Diversity
  - United Nations Convention to Combat Desertification
  - Ramsar Convention on Wetlands
  - Convention on Migratory Species
- Also designed to meet needs of other stakeholders, including the business community, the health sector, nongovernmental organizations, and indigenous peoples



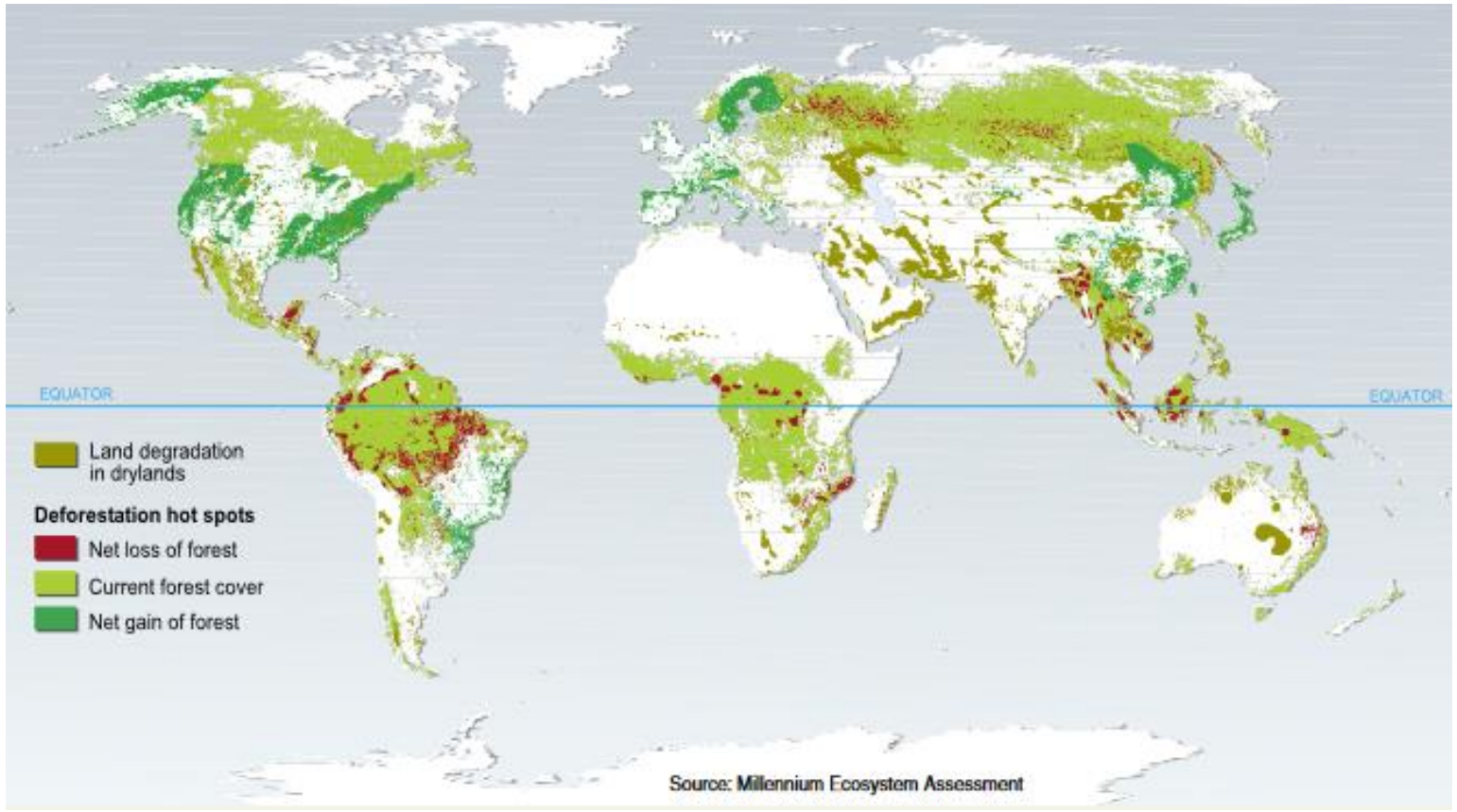



Five Questions of the MEA

- What are the current conditions and trends of ecosystems, ecosystem services, and human well-being?
- What are plausible future changes in ecosystems and their ecosystem services and the consequent changes in human well-being?
- What can be done to enhance well-being and conserve ecosystems? What are the strengths and weaknesses of response options that can be considered to realize or avoid specific futures?
- What are the key uncertainties that hinder effective decision-making concerning ecosystems?
- What tools and methodologies developed and used in the MA can strengthen capacity to assess ecosystems, the services they provide, their impacts on human well-being, and the strengths and weaknesses of response options?
  - Earth Observations are one of those tools

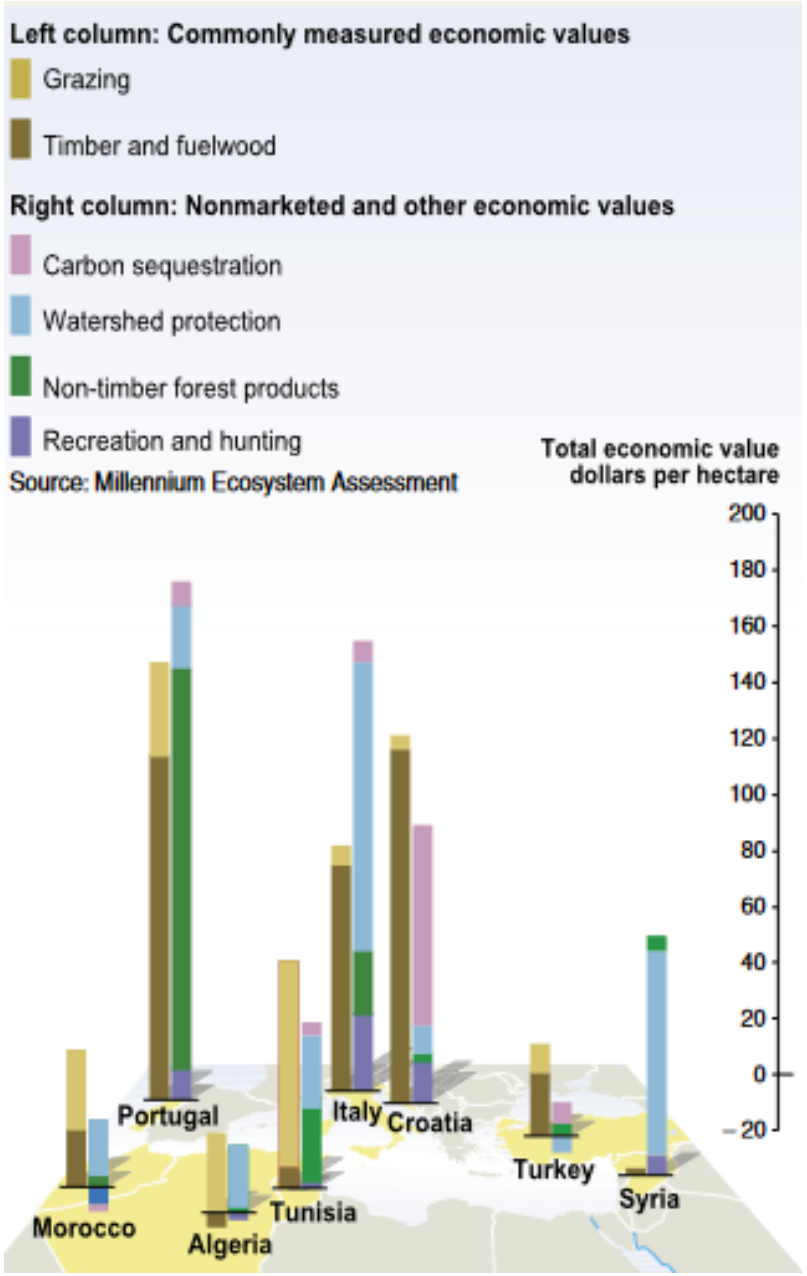
Findings of the MEA

- Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.



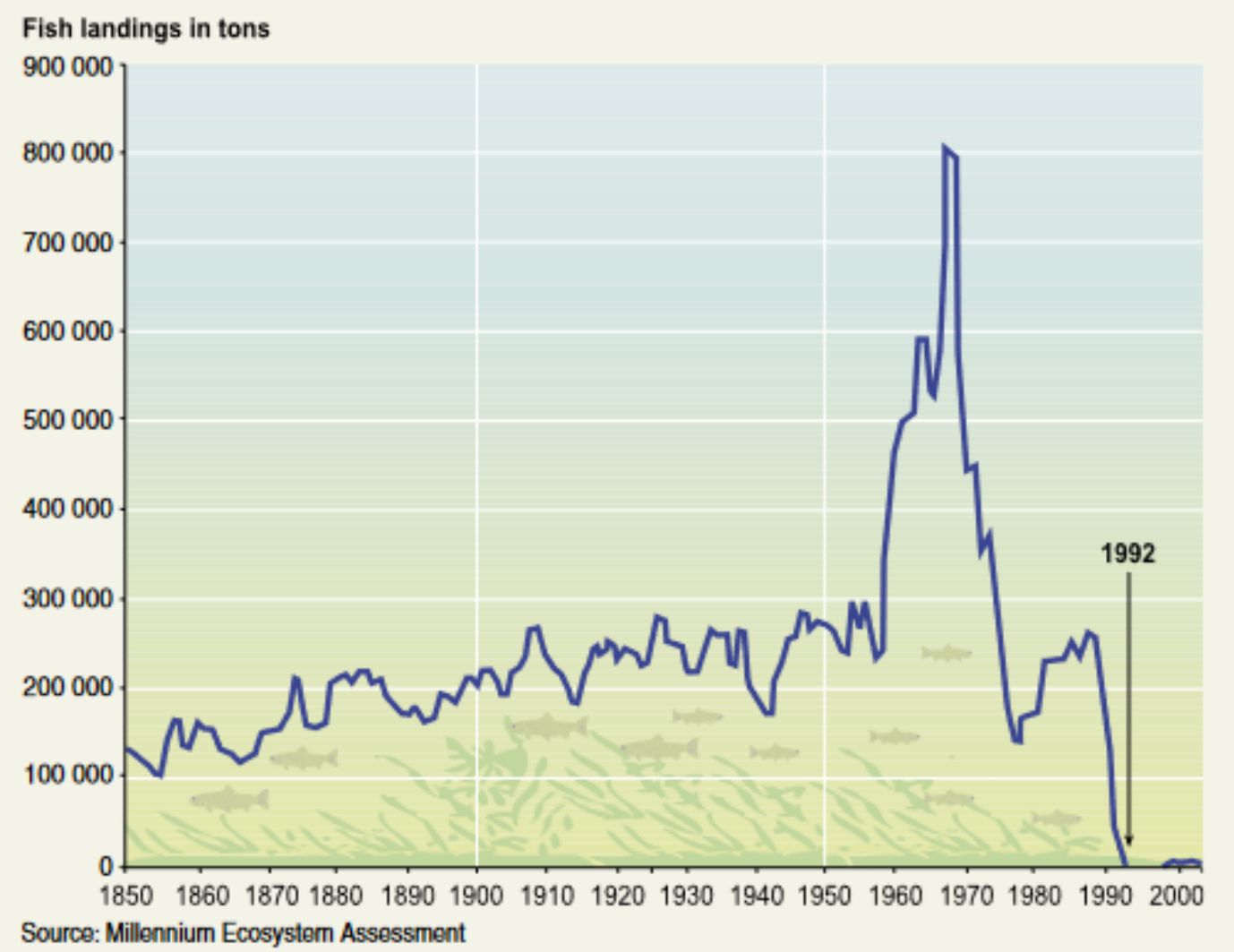
Findings of the MEA

- Ecosystem changes:
  - Contributed to substantial net gains in human well-being and economic development
  - Gains have been achieved at growing costs in the form of the degradation of many ecosystem services, increased risks of nonlinear changes, and the exacerbation of poverty for some groups of people



Findings of the MEA

- The degradation of ecosystem services could grow significantly worse during the first half of this century and is a barrier to achieving the Millennium Development Goals.



Findings of the MEA

- The challenge of reversing the degradation of ecosystems while meeting increasing demands for their services can be partially met under some scenarios that the MA has considered, but these involve significant changes in policies, institutions, and practices that are not currently under way.
  - Significant progress in policies, institutions, and practices since 2005




Ecosystem Service Valuation

Ecosystem Service Valuation

- The process of quantifying the value of the ecosystem service benefits to people provided by a given landscape or habitat type in a defined location.
  - Can be challenging and controversial
  - Important to define the purpose of the valuation
  - Need to recognize that in engaging in the process of valuation, you are making a kind of ethics trade-off
  - Indigenous communities already have value systems: just recognizing value, spiritual, etc.
- Can be economic or non-economic

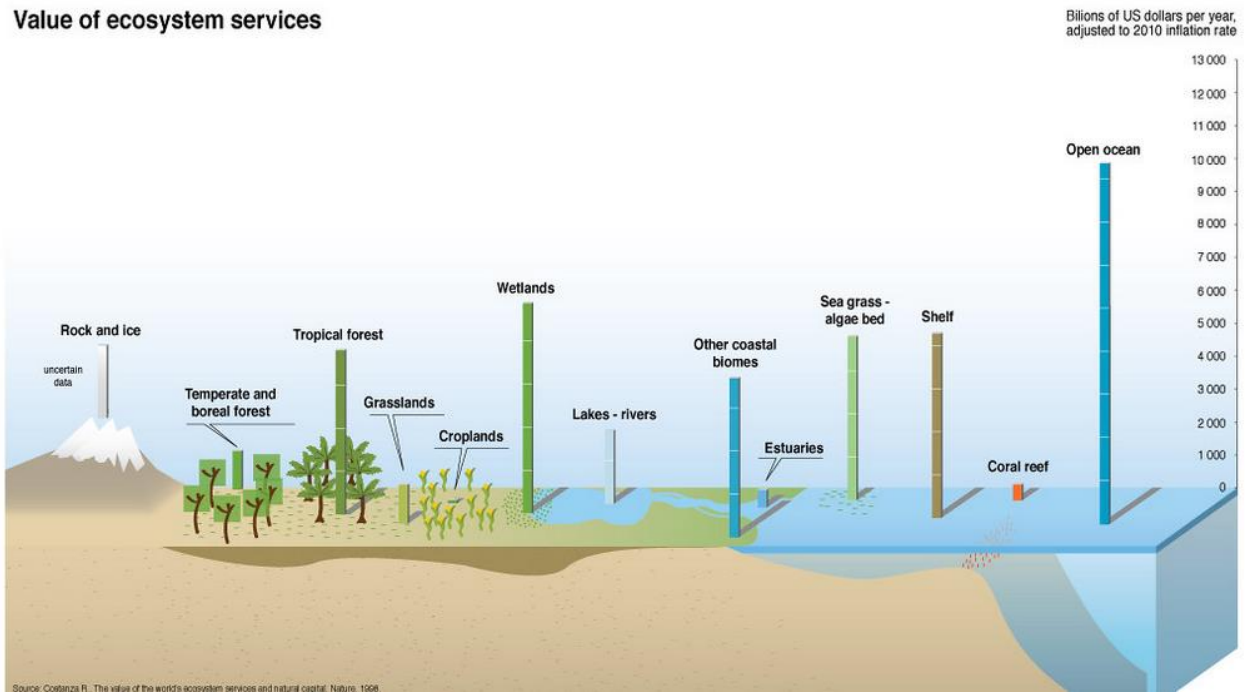


Image Credit: Modified from Constanza, et al 1997

Economic Ecosystem Service Valuation

- Ascribing monetary values, ascribing economic quantities to what nature is delivering in terms of ecosystem services and biodiversity
  - Need to look at local level
  - Valuation is not pricing
  - Value is what you receive, price is what you pay
- Valuation is locally and contextually specific
- Dynamics of ecosystem can change over time due to things like climate change or increased management/use
- Total Economic Value (TEV) Framework
  - See Department for Environment, Food and Rural Affairs, 2007 Publication

What is Natural Capital?

- "Natural capital is another term for the stock of renewable and non-renewable resources (e.g., plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people." (Natural Capital Coalition)
  - Woodland = Natural Capital Asset
    - Valuable benefits or ecosystem services such as flood risk reduction and carbon capture
- Geospatial and remote sensing data can play a role in natural capital assessments.

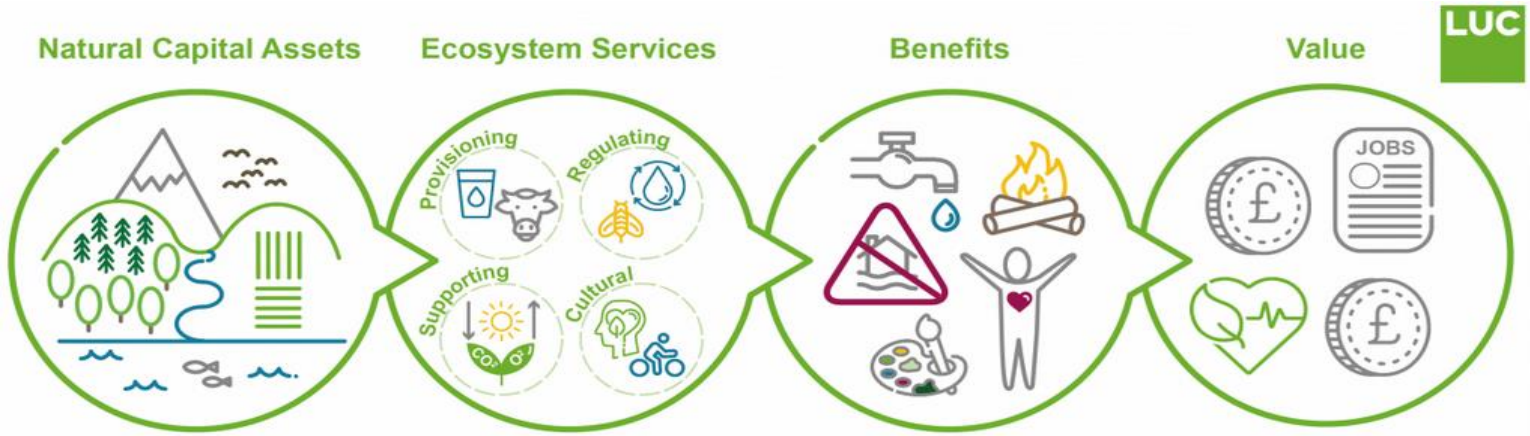
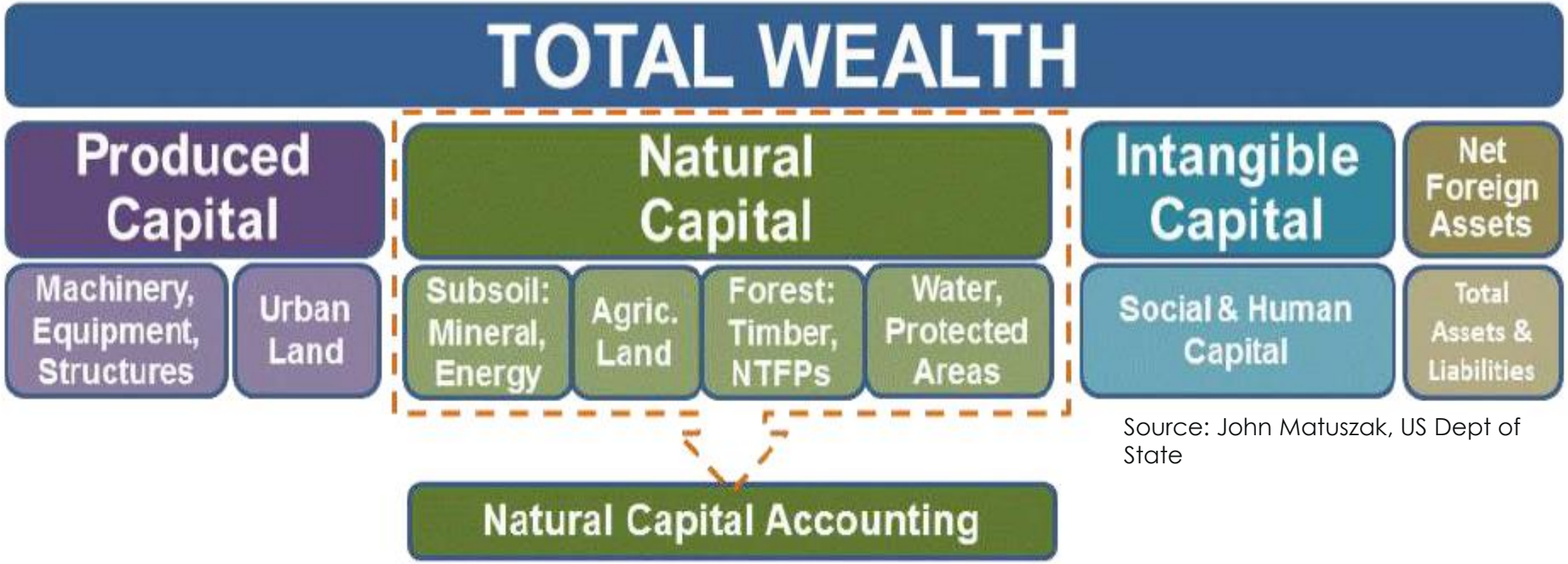


Image Credit: landuse.co.uk

What is Natural Capital Accounting (NCA)?

- "A coherent and integrated approach to the assessment of the environment through the measurement of ecosystems, and measurement of the flows of services from ecosystems into economic and other human activity" (SEEA EEA 2012).
  - Measures the value of ecosystems (stocks) and the services they provide (flows)
  - Integrates this information into accounting systems that governments already use in their decision making
  - Provides a more complete view of a country's assets

What is Natural Capital Accounting (NCA)?



Source: John Matuszak, US Dept of State

Benefits of Natural Capital Accounting

- Allows governments to account for nature's role in the economy and human well-being
  - Indicators for monitoring sustainable development
- Tools for managing natural capital to promote growth and poverty reduction
- Enables businesses to become more efficient and sustainable

Image Credit: National Geographic

Image Credit: Thoughtco

Image Credit: Nationaltoday

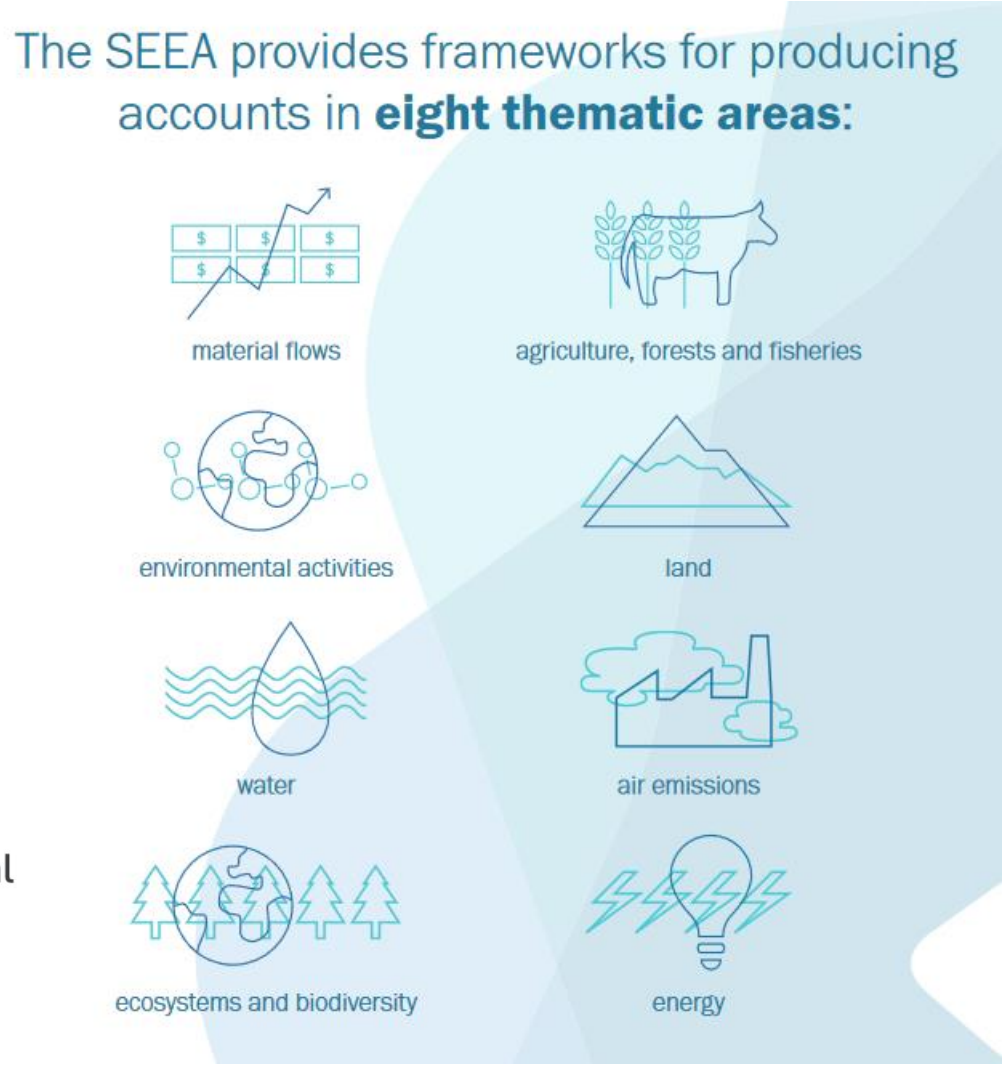
Global Frameworks and Initiatives for Assessing Value of Ecosystems

The UN System of Environmental-Economic Accounting (SEEA)

- A methodology for NCA
- The SEEA is the internationally accepted statistical framework to measure the environment and its interactions with economy and as such, it is a fundamental planning policy tool for national governments aspiring towards sustainable development.

United Nations

System of Environmental Economic Accounting

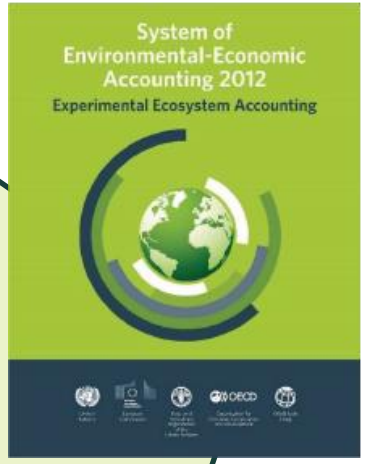


SEEA Central Framework and Ecosystem Accounting

Asset & Resources + Ecosystems = SEEA

Measures environmental assets and individual resources and how the economy used them.

Measures ecosystems and the services they provide to economic and human activity.



Source: Modified from Alfieri, A. Presentation to Africa NCA CoP (June 2020)

Ecosystem Accounts (EA)

- The systematic framework to measure the contributions of ecosystems to economic activity
  - Rely on spatial data in order to systematically assess the health and status of ecosystems and the benefits of ecosystem flows to human well-being and the economy

Image Credit: SEEA

SEEA Ecosystem Accounting (SEEA EA)

- Integrated and comprehensive statistical framework for organizing data about habitats and landscapes, measuring the ecosystem services, tracking changes in ecosystem assets, and linking this information to economic and other human activity.
  - Applies national accounting principles: use of environmental data on ecosystems in economic decisions making

Image Credit: System of Environmental Economic Accounting (SEEA) Water

SEEA EA: A Spatial Approach

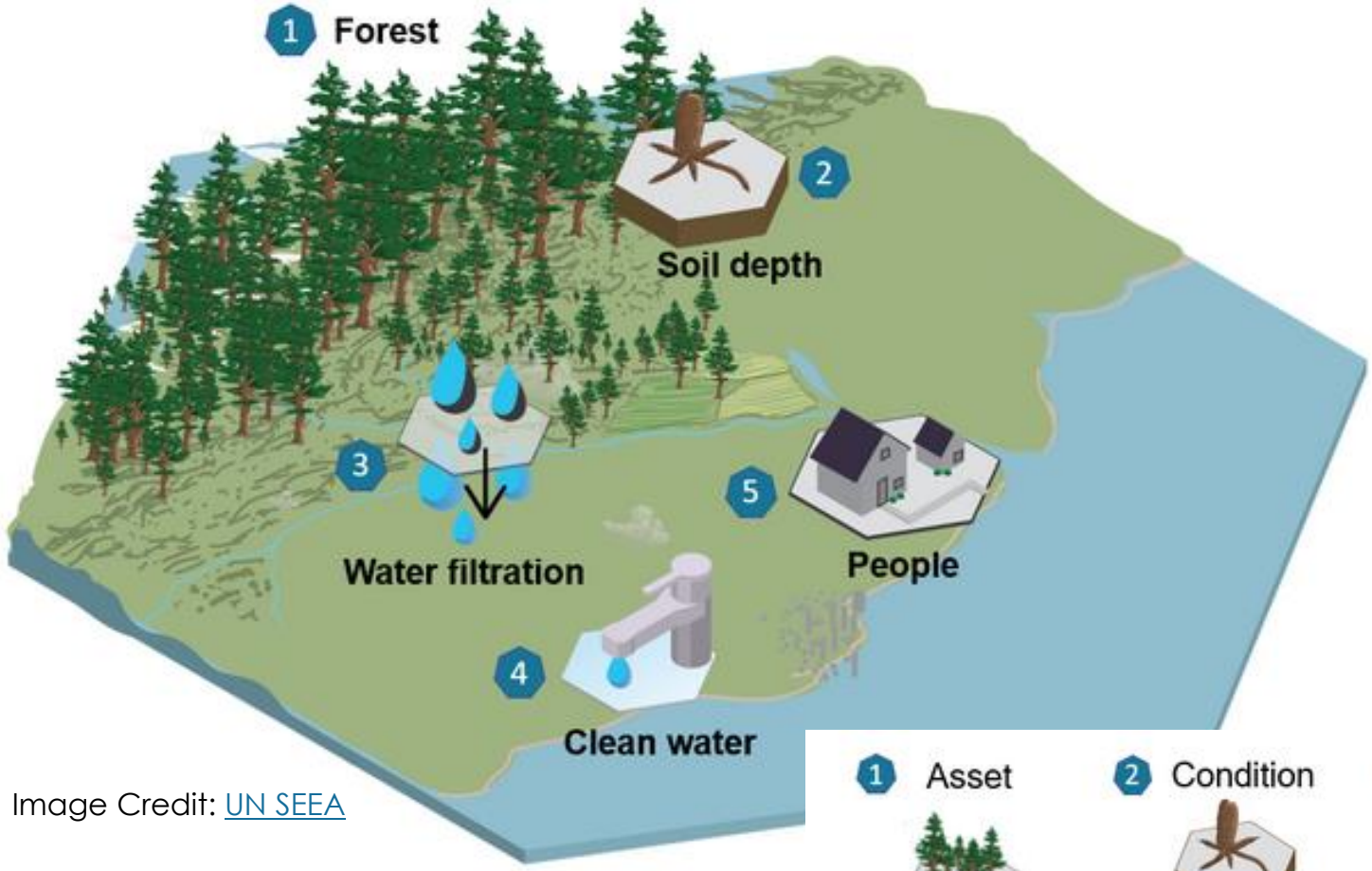


Image Credit: UN SEEA

- Spatial Approach: Benefits depend on where assets are in the landscape in relation to beneficiaries
- Use Maps: Remote sensing
- Can be compiled at varying spatial scales

SEEA EA Core Components

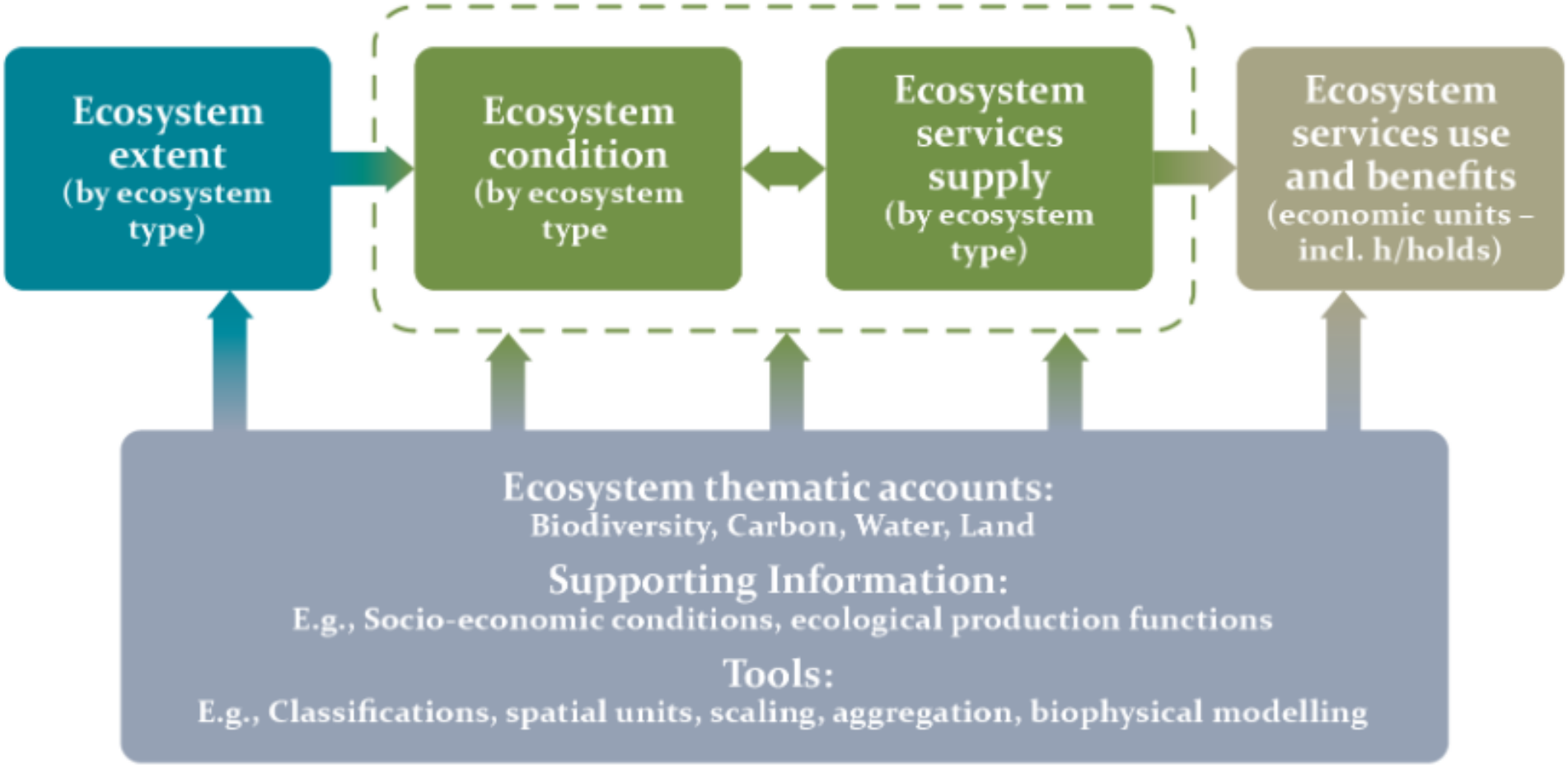
1. ECOSYSTEM EXTENT accounts record the total area of each ecosystem, classified by type, within a specified area (ecosystem accounting area), measured over time.

2. ECOSYSTEM CONDITION accounts record the condition of ecosystem assets in terms of selected characteristics at specific points in time. Over time, they record the changes to their condition and provide valuable information on the health of ecosystems.

3. & 4. ECOSYSTEM SERVICES flow accounts (physical and monetary) record the supply of ecosystem services by ecosystem assets and the use of those services by economic units (including households).

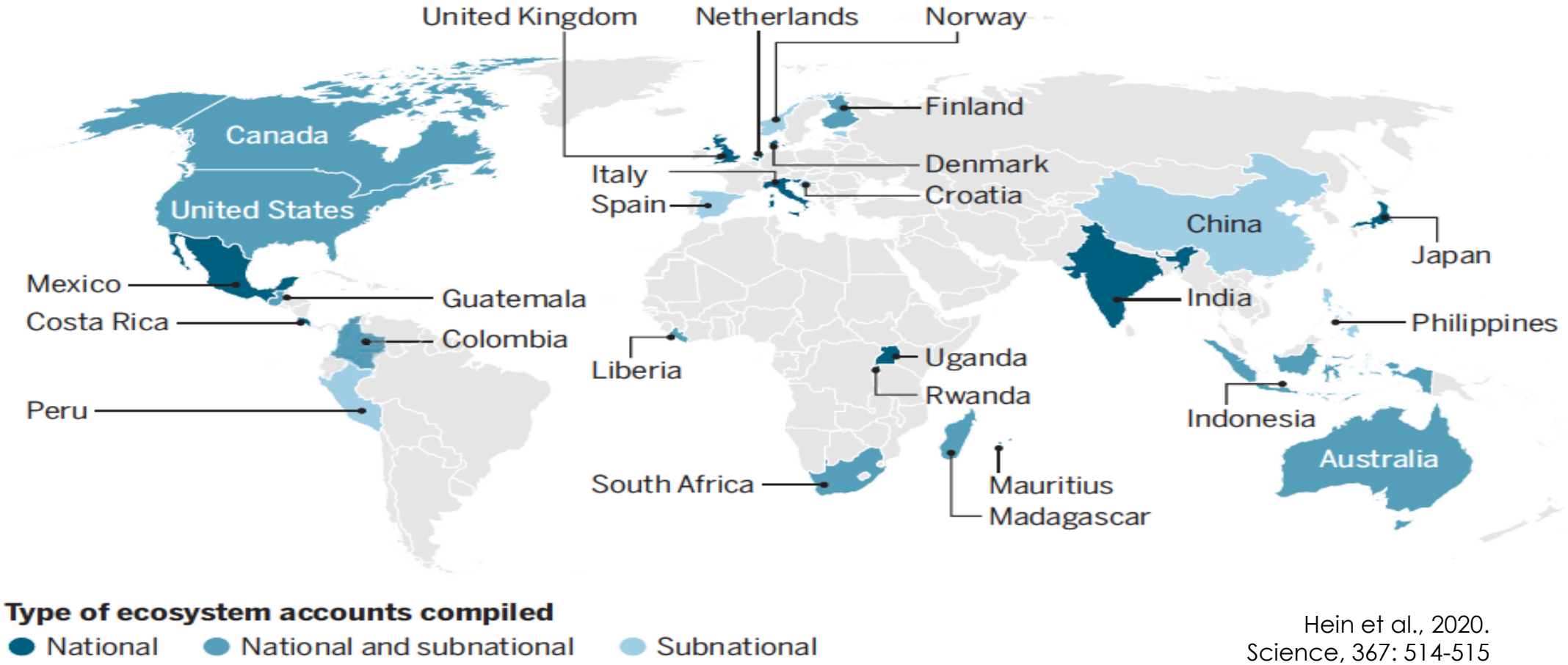
5. MONETARY ECOSYSTEM ASSET accounts record information on stocks and changes in stocks (additions and reductions) of ecosystem assets. This includes accounting for ecosystem degradation and enhancement.

SEEA Applications and Policy



Source: Adapted by Chow 2016, found in UNEP-WCMC & IDEEA Technical Report

SEE EA Implementation Progress



Hein et al., 2020.
Science, 367: 514-515

SEEA EA Challenges and Opportunities

Challenges:

- Variability in scope and level of spatial data
- Require substantial data and use of multiple biophysical models
- Data may be in incompatible formats or there may be a reluctance to share it
- Different measurement approaches compared to other systems
- Ecosystem diversity makes selection of condition and biodiversity indicators challenging
  - Current EAs don't include ecosystem resilience or probabilities for ecosystem collapse from overuse
- Reflect current pricing and markets

Opportunities:

- UNSC establishing statistical standards
- Working groups addressing remaining technical issues
- Group on Earth Observations (GEO) examining use of remote sensing (more on next few slides)
- Large datasets being made to many users, models, and cloud computing
- The system allows for comprehensive and high-resolution analysis and reporting on ecosystems and their use

Points adapted from Hein et al., 2020. Science, 367: 514-515

Group on Earth Observations (GEO)

- An intergovernmental partnership working to improve the availability, access, and use of open Earth observations, including satellite imagery, remote sensing, and in situ data to impact policy and decision making in a wide range of sectors.
- GEO promotes open, coordinated, and sustained data sharing and infrastructure for better research, policy making, decisions, and action across many disciplines.
- Three global priority engagement areas:
  - The United Nations 2030 Agenda for Sustainable Development
  - The Paris Agreement
  - The Sendai Framework for Disaster Risk Reduction



Image Credit: GEO

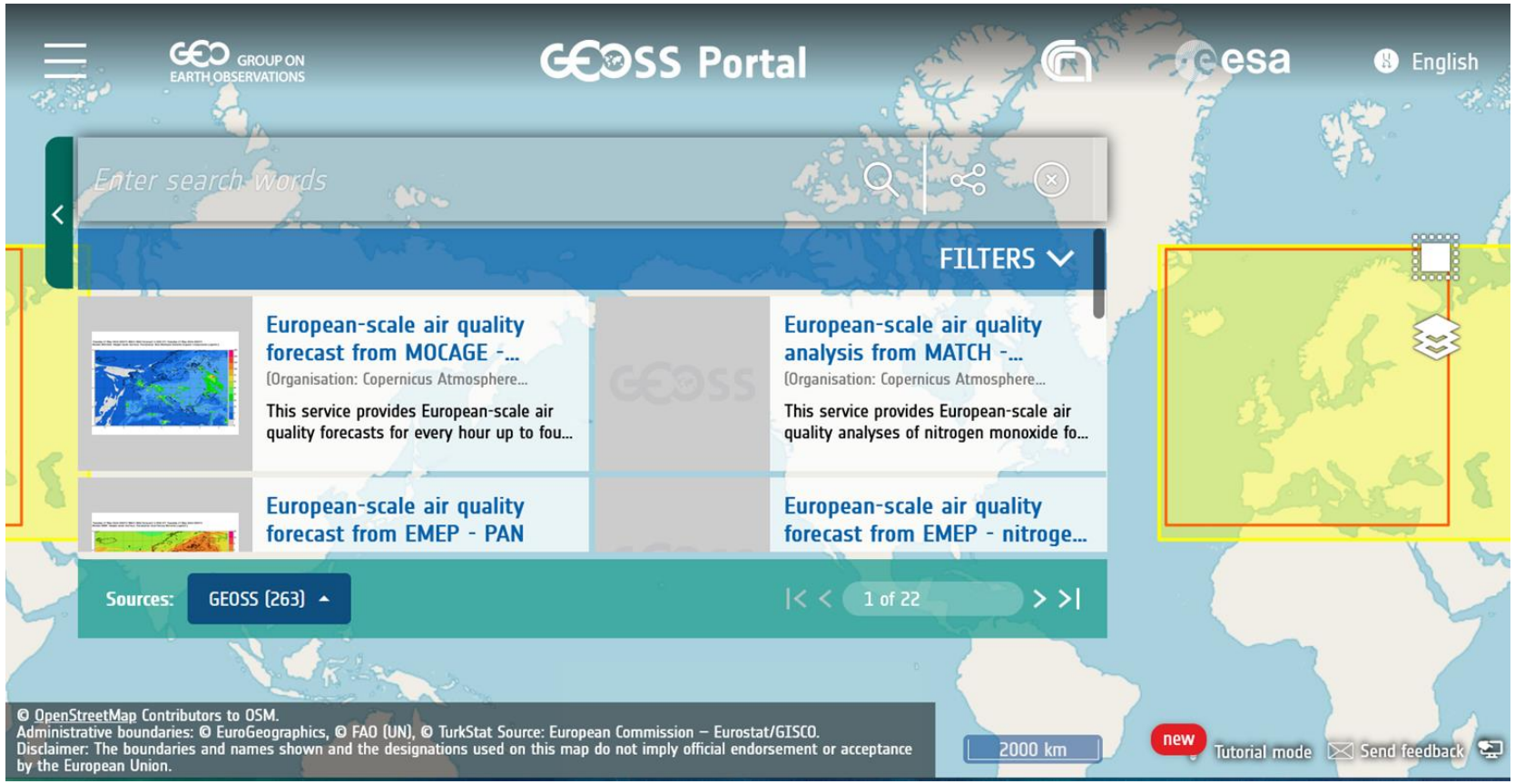
Global Earth Observation System of Systems (GEOSS)

- GEOSS is a set of coordinated, independent Earth observation information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors.
- Facilitates the sharing of environmental data and information collected from the large array of observing systems
- Ensures that these data are accessible, of identified quality and provenance, and interoperable to support the development of tools and the delivery of information services

GEO GROUP ON EARTH OBSERVATIONS

GEOSS Portal

- An online, map-based user interface which allows users to discover and access Earth observation data and resources from different providers from all over the world.



https://www.geoportal.org/

Earth Observations for Ecosystem Accounting (EO4EA)

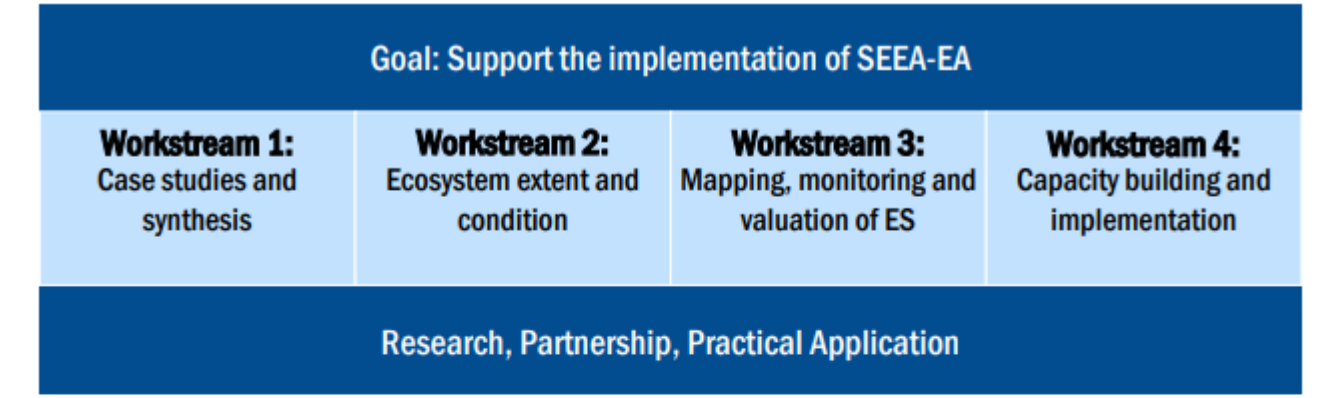
Using the power of Earth observations (EO) to establish accounting systems for nature

- **Vision:** A future where EO enables environmental transparency and the true value of ecosystems is incorporated into conventional economic accounts and decision making, leading to a radical shift in the appreciation and valuation of natural resources.
- **Mission:** Document, pioneer, develop, and test the methods and tools that will allow earth observation technology to more effectively enable the widespread adoption of ecosystem accounting.
- **Membership:** Include national governments, academic institutions, intergovernmental organizations, and NGOs.

EARTH OBSERVATIONS FOR ECOSYSTEM ACCOUNTING

Earth Observations for Ecosystem Accounting (EO4EA)

Workstreams



Deliverables

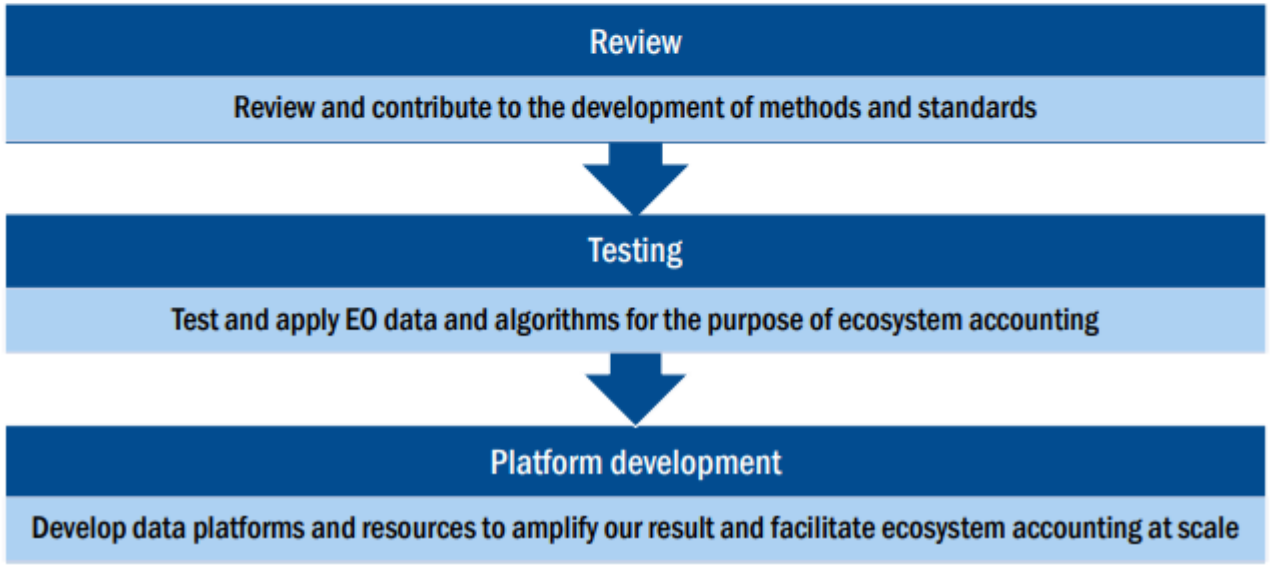


Image Credit: EO4EA, Daniel Juhn, CI

Gaborone Declaration for Sustainability in Africa (GDSA)

- A commitment to a new model of development that, for the first time, takes into account the role of natural capital in development by bringing the value of natural resources from the periphery to the center of all economic decision-making.

Image Credit: Conservation International

Image Credit: Rod Mast

Image Credit: Will Turner

Image Credit: CI/John Martin

Gaborone Declaration for Sustainability in Africa (GDSA)

1. Countries must **integrate the value of nature into their national policies and programs**, recognizing that nature is needed for economic growth and sustainability.
2. Countries must reduce poverty by **transitioning agriculture, extractive industries, fisheries, and other economic uses of nature to practices that promote sustainable employment, food security, sustainable energy, and the protection of nature**, including protected areas.
3. Countries must build the knowledge, capacity, and policy networks to **promote leadership and a new model in the field of sustainable development** to increase momentum for positive change.

GDSA and Conservation International (CI)

- Conservation International (CI) is the Secretariat of GDSA and provides:
  - Outreach and communications to countries and partners
  - A framework for implementation
  - Funding opportunities
  - Support of the development of projects and monitoring progress
  - Promotion of successes and encouraging further efforts to incorporate the value of nature in economic and social development decisions

https://www.conservation.org/projects/gaborone-declaration-for-sustainability-in-africa

Wealth Accounting and the Valuation of Ecosystem Services (WAVES)

https://www.wavespartnership.org/en

- A World Bank-led global partnership that aims to promote sustainable development by ensuring that natural resources are mainstreamed in development planning and national economic accounts.
- Part of the Global Program for Sustainability (GPS)
  - Aim to integrate environmental and other sustainability considerations into public and private decisions, by providing metrics and tools

Tsefaye Kidane, a 40-year-old coffee farmer from the Kafa Biosphere Reserve in southwest Ethiopia. Photo Credit: Kaia Rose, Connect4Climate – World Bank Group

GPS Global Program on Sustainability

WAVES

WAVES Objectives

- Help countries adopt and implement accounts that are relevant for policies and compile a body of experience
- Develop approaches to ecosystem accounting methodology
- Establish a global platform for training and knowledge sharing
- Build international consensus around natural capital accounting

Working with many member countries such as:

- Botswana
- Colombia
- Costa Rica
- Guatemala
- Indonesia….and many more!

Indonesia (top) and Costa Rica (left): Image Credit: World Bank

Remote Sensing Data for Ecosystems Services

Remotely-Sensed Data for Ecosystem Services

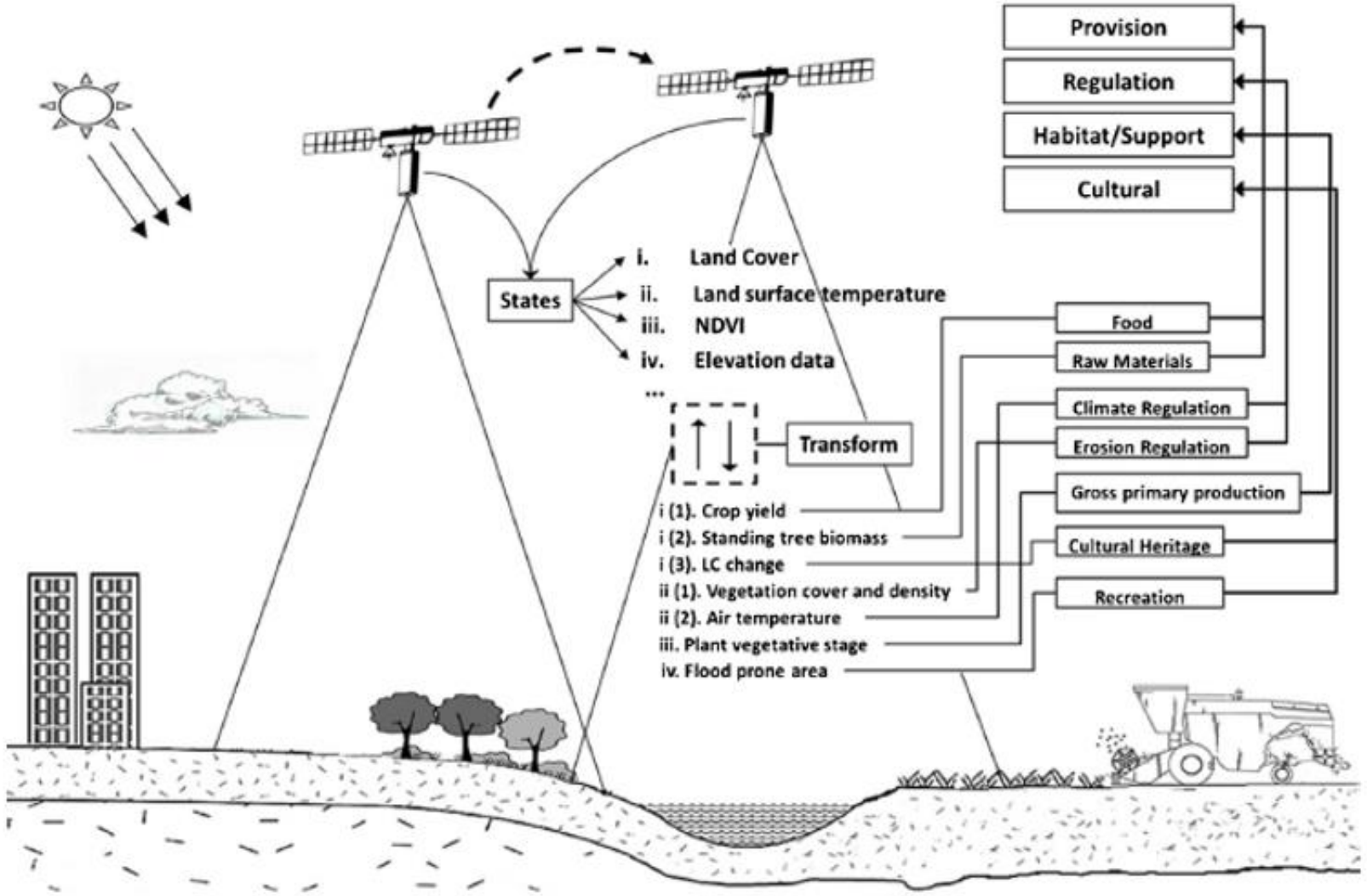
- Spatial Data used in 80% of assessments
- Earth Observations (EO) are an important tool
- Benefits to use of EO:
  - Spatially Explicit
  - Rapid Assessment: Becoming more easily available over multiple platforms
  - Cost Effective
  - Regular, Repeatable Observations
  - Access to Remote Locations
  - Global (mostly)

Remotely-Sensed Data for Ecosystem Services

- Land Cover Mapping: Proxy assessment of ecosystem characteristics
- Change Monitoring
- Additional Biophysical Information:
  - Elevation
  - Climate Variables
    - Precipitation
    - Temperature
  - Hydrology/Water Cycle
  - Primary Productivity
  - Carbon Storage
  - Canopy Structure
  - Woody Biomass

Mangroves, Image Credit: ESA

Spatial and Remotely-Sensed Data for Ecosystem Services



The generation of remotely sensed data into ecosystem service values and flows (De Araujo Barbosa *et al.*, 2015)

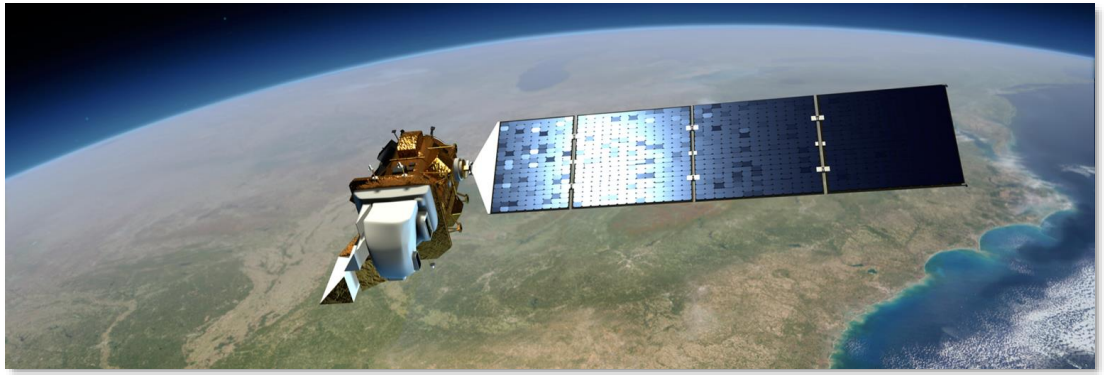
Satellites and Sensors for Ecosystem Services

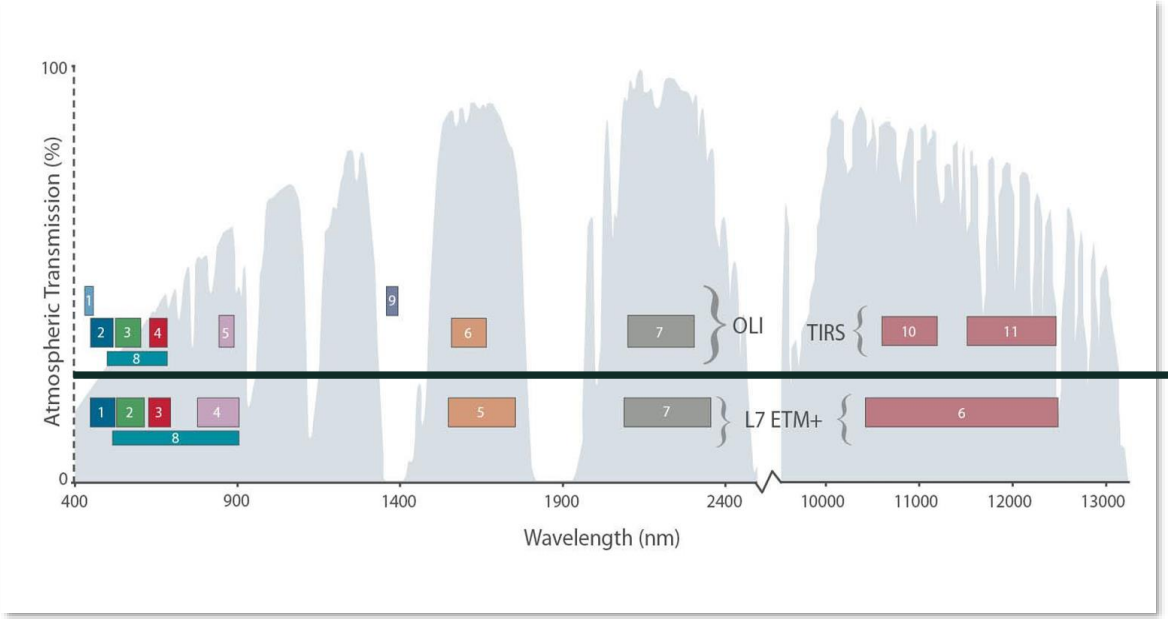
- Landsat
- Sentinel-2
- MODIS
- VIIRS
- AVHRR
- Hyperion
- Sentinel-1
- ALOS/PALSAR

Sentinel-2 (top), Terra MODIS (right)

Landsat

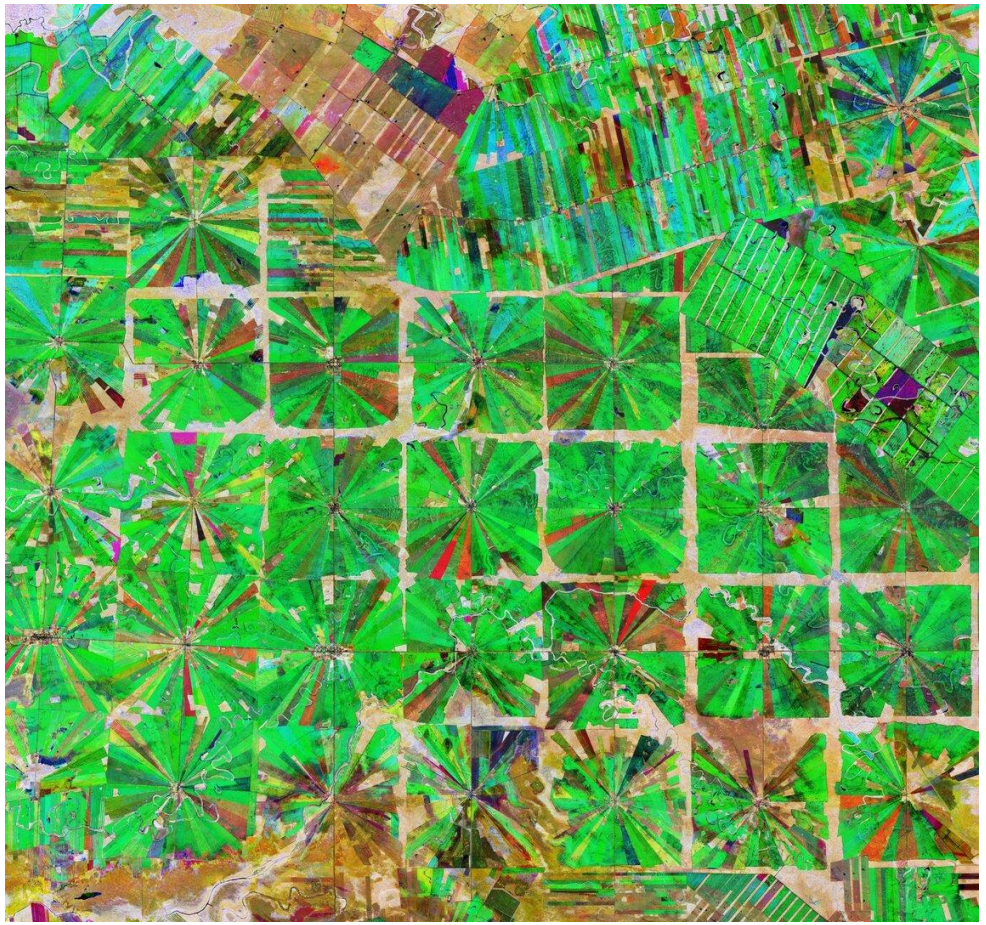
- First Landsat launched in 1972
- Landsat 8 launched in 2013
- NASA created and launched
  - USGS maintains data
- Passive Sensor - Obtains values of reflectance from Earth's surface
- 30-meter pixels, 15-meter panchromatic band
- Image of the entire Earth every 16 days





Sentinel-2

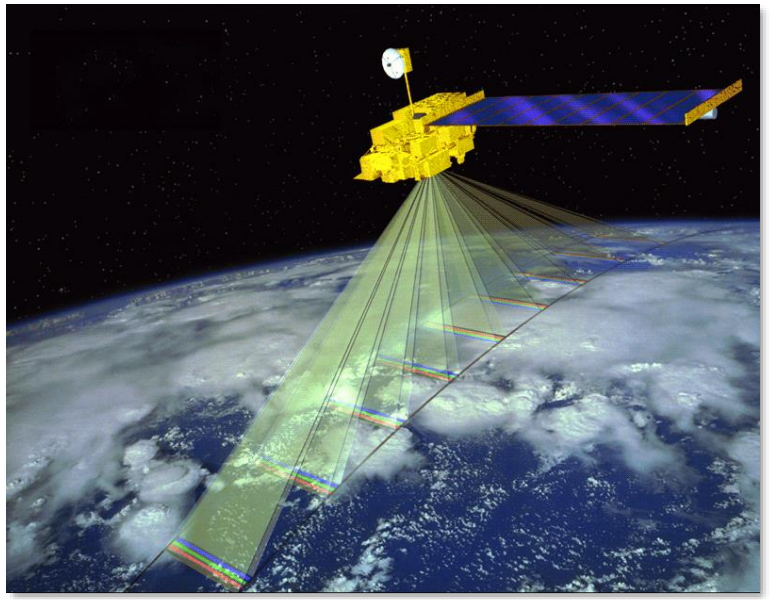
- Launched in 2015
- 13 spectral bands
- Spatial Resolution:
  - Red, Green, Blue (RGB) at 10 meters
  - Near-Infrared and Shortwave Infrared at 20 and 60 meters
- Revisit Time: ~5 days
- Often combined with Landsat for continuity
  - Harmonized Sentinel-2 and Landsat surface reflectance products available

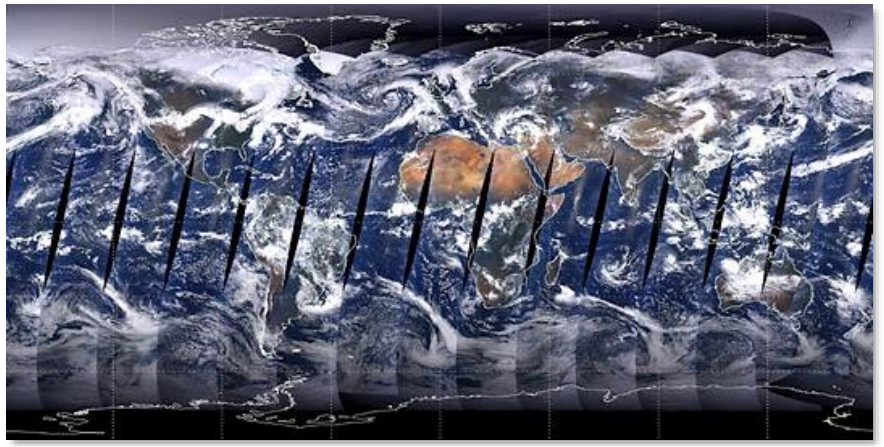


Composite Sentinel-2 image of forests converted to farmland in Brazil, 2019. Image Credit: ESA

Moderate Resolution Imaging Spectroradiometer (MODIS)

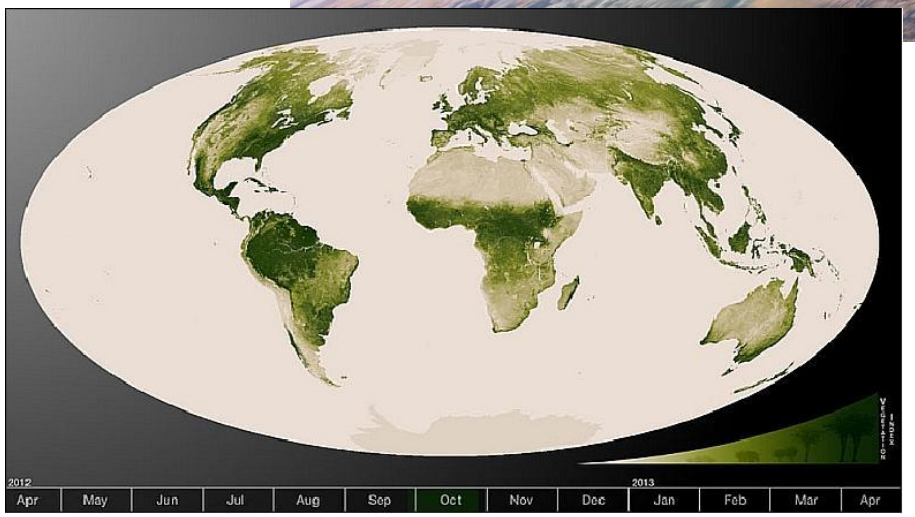
- Spatial Resolution:
  - 250 m, 500 m, 1 km
- Temporal Resolution:
  - Daily, 8-day, 16-day, monthly, quarterly, yearly
  - 2000–Present
- Data Format:
  - Hierarchical Data Format – Earth Observing System Format (HDF–EO8)
- Spectral Coverage:
  - 36 bands (major bands include blue, green, red, IR,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





Visible Infrared Imaging Radiometer Suite (VIIRS)

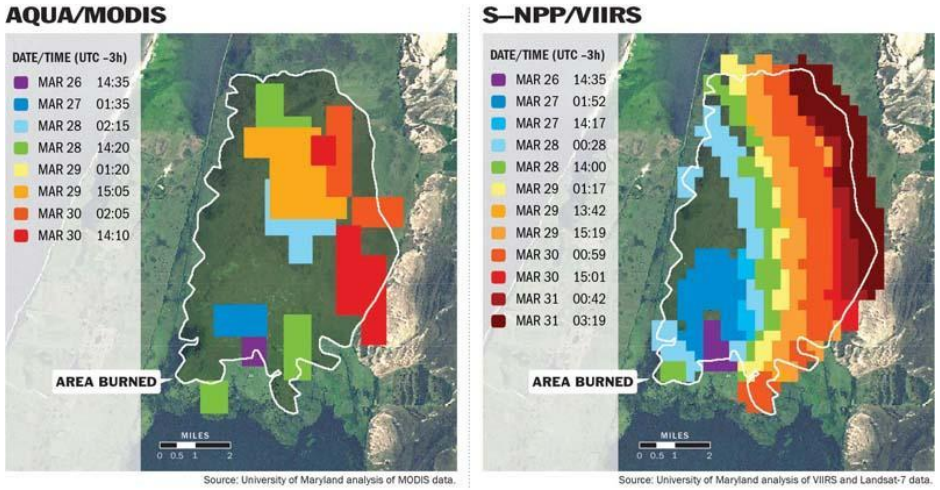
- A sensor onboard the Suomi National Polar-Orbiting Partnership (NPP)
- Data available globally from January 2012 to present
- Revisit Time: 1 Day
- Spatial Resolution: 375 m and 750 m
- Similar to MODIS (with some differences)
- Visible, near-infrared channels (reflectance)
- Shortwave and longwave infrared (brightness temperature)
- Products:
  - Surface Reflectance
  - Vegetation Indices
  - Thermal Anomalies

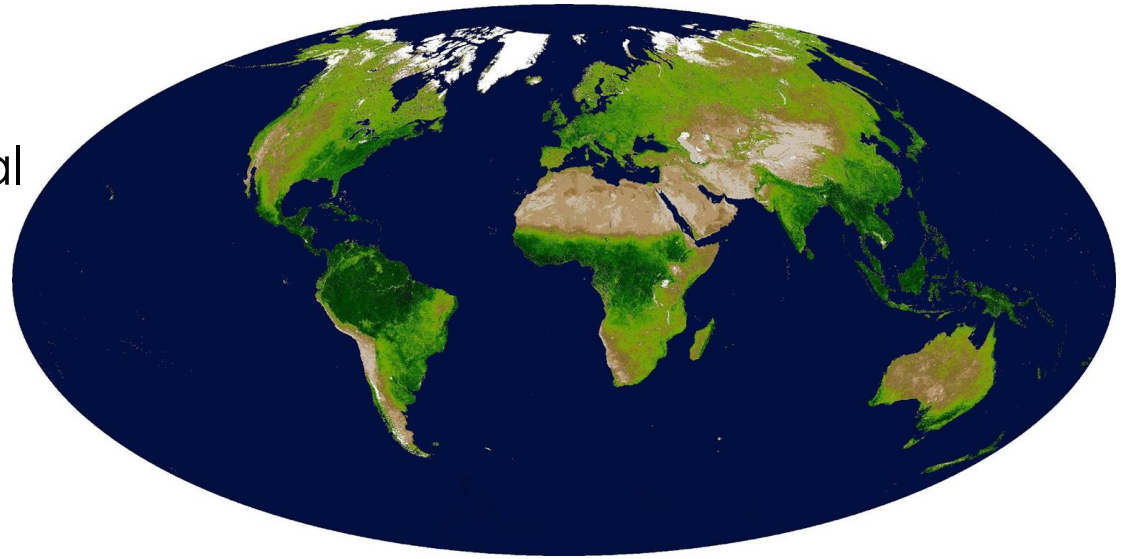


Suomi NPP Satellite (above); Global Vegetation Map (left). Image Credit: NASA/NOAA)

MODIS to VIIRS Transition

- Improved Spatial Resolution -
  - From 500 m and 1000 m to 375 m and 750 m
- Spectral Coverage Slightly Smaller -
  - From 0.412 – 14 microns to .412 to 12 microns
- Fewer Bands -
  - From 36 to 22
- Higher Orbit – Absolute full global coverage in one day
- Comparable Radiometric and Spectral Quality -
  - 12-bit data
  - Similar on-board calibrators



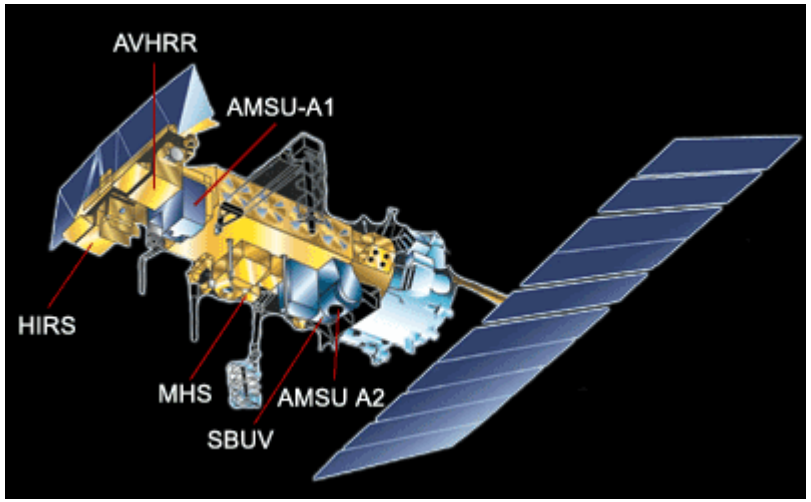


MODIS vs. VIIRS burned area from Brazil in 2013 (above), Image Credit: University of Maryland;

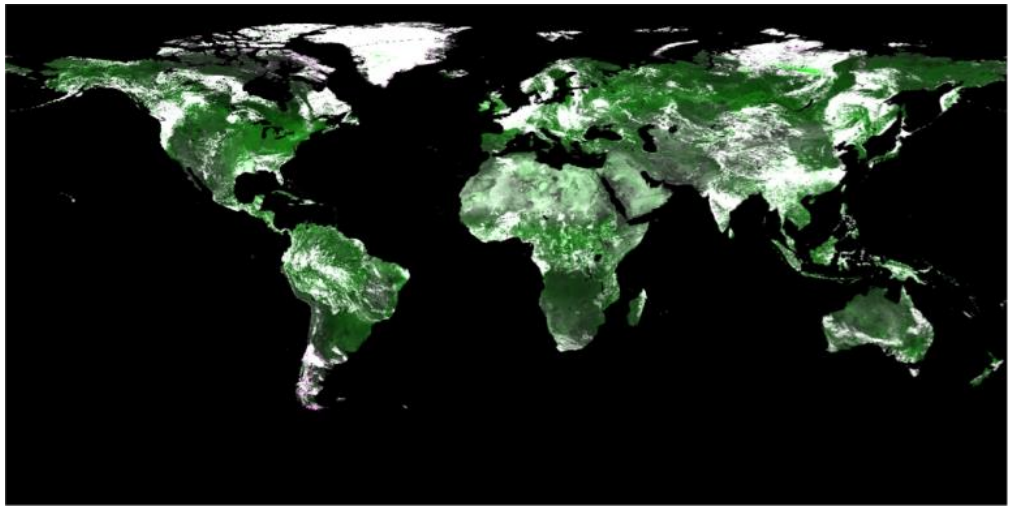
EVI from MODIS (left), Image Credit: NASA

Advanced Very High-Resolution Radiometer (AVHRR)

- Produced and operated by the National Oceanic and Atmospheric Administration (NOAA)
- Onboard many NOAA Polar Orbiting Environmental Satellites (POES)
  - Data available from 1978 to present
- Spatial Resolution: 1 km
- Temporal Resolution: Global coverage available twice daily (morning and afternoon)
- Spectral Resolution: 4-6 bands, multispectral, visible, near-infrared, and thermal bands
- Land cover and vegetation index products available



NOAA's N instrument, with the AVHRR sensor included. Image Credit: NOAA



Surface reflectance from AVHRR (global, 1km). Image Credit: NOAA

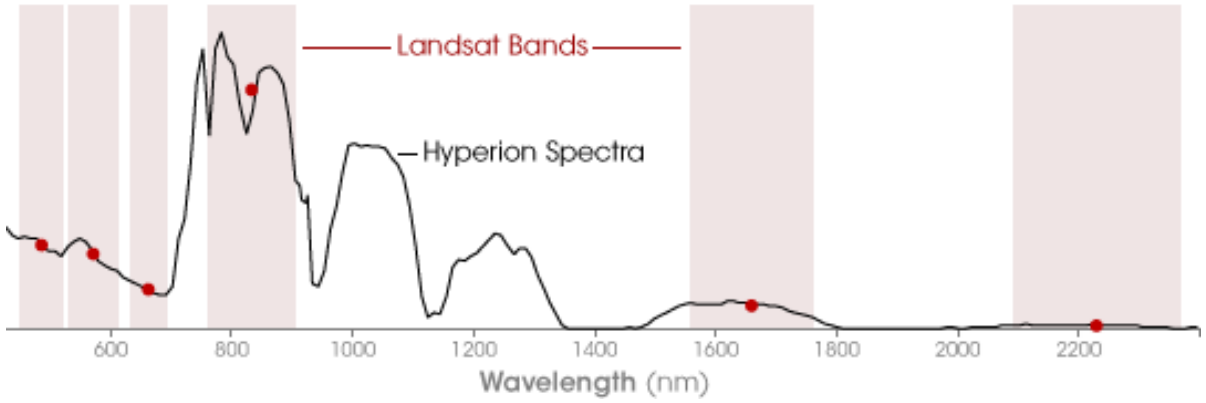
SPOT and MERIS

- **SPOT (Multiple Satellites)**
  - National Centre for Space Studies (*CNES*), French government space agency
  - Spot 6 (2012), 7 (2014)
  - 6-meter spatial resolution
  - Revisit Time: ~2-3 days
- **Medium Resolution Imaging Spectrometer (MERIS)**
  - ESA sensor onboard the Envisat satellite
    - Launched in 2002, ended in 2012
    - Full Resolution Data: 300 m spatial resolution acquired regionally
    - Global coverage every 3 days
  - Land cover mapping, vegetation health, drought applications
  - MERIS Global Vegetation Index (MGVI), which corresponds to the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)

FPAR over Europe from 2006. Image Credit: ESA

EO-1 Hyperion

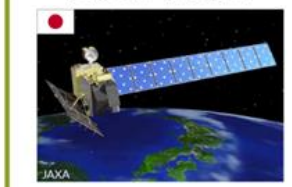
- Date Range: 2000-2017
- 220 spectral bands
- 357 to 2567 nm
- 10 nm bandwidth
- 30 m spatial resolution
- 7.75 km swath
- 12-bit



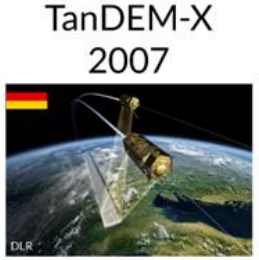
Hyperion image of Mount. Fuji, 2000 (left), the Hyperion sensor (top), and a comparison of the Landsat bands and a spectra from Hyperion. Image Credit: USGS

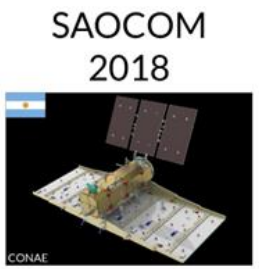
Radar Data Available

Legacy:

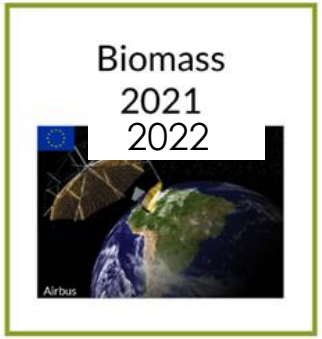


Current:





Future:



Freely Accessible

Image Credit: Franz Meyer, University of Alaska, Fairbanks

Remotely-Sensed Data Products for Ecosystems Services

Data Products for Ecosystem Services

- Land Cover Maps for Ecosystem Extent
- Ecosystem Conditions
  - Phenology
  - NDVI, EVI
  - Leaf Surface Area/Index
  - NPP
  - Slope/Elevation
  - Damage Impacts
- Ecosystem Structure (LiDAR, SAR)
  - Vegetation Height (limited standardized products, one for boreal forests)
  - Do your own analysis:
    - SERVIR SAR Handbook: https://servirglobal.net/Global/Articles/Article/2674/sar-handbook-comprehensive-methodologies-for-forest-monitoring-and-biomass-estimation

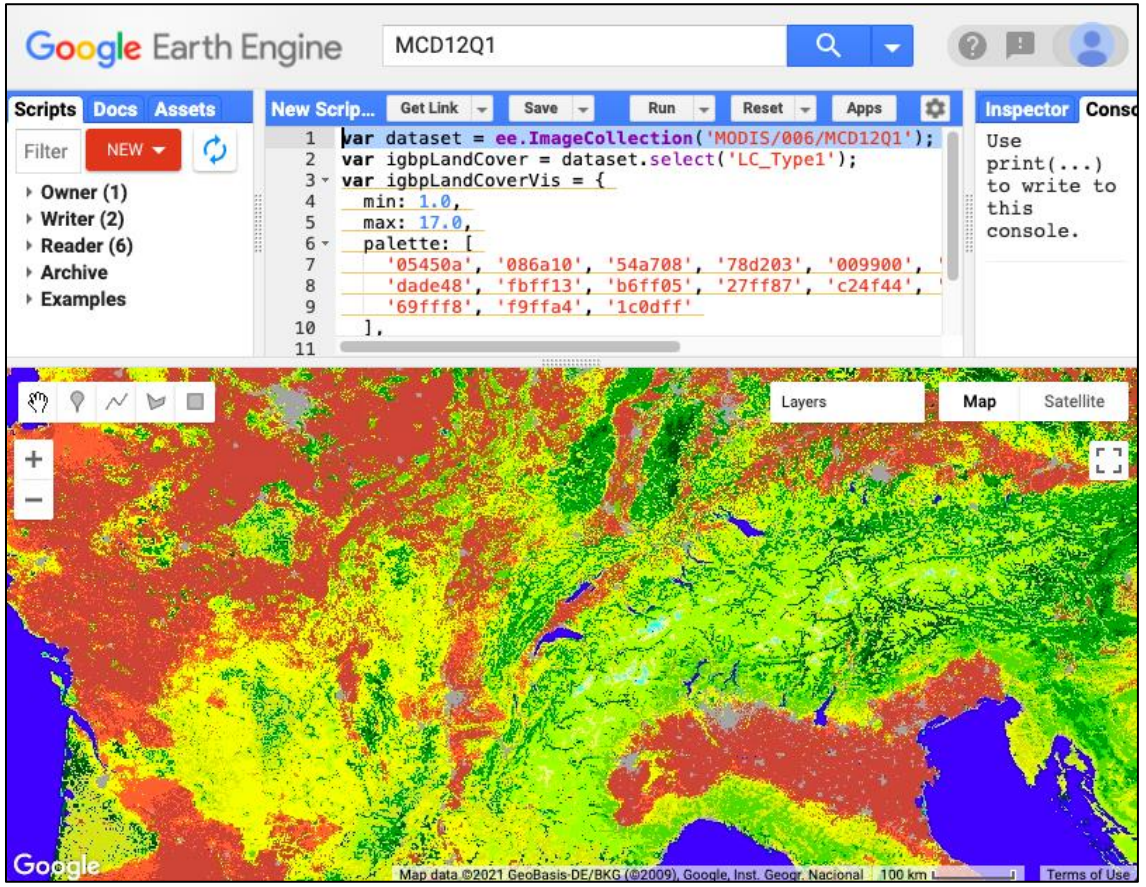
Land Cover Classification Overview

- Important for the establishment of an environmental baseline
- Land cover classification is the process of grouping spectral classes and assigning them informational class names.
- Spectral Classes:
  - Groups of pixels that are uniform with respect to their pixel values in several spectral bands
- Informational Classes:
  - Categories of interest to users of the data (like water, forest, urban, agriculture, etc.)

Classic example of a land cover assessment from the USGS National Land Cover Database. Image Credit: USGS

Create Your Own Land Cover Map

- Beneficial if you have local data/knowledge
- Can be conducted in a variety of GIS software or in Google Earth Engine
- Previous ARSET trainings:
  - Land Cover Classification with Satellite Imagery
  - Accuracy Assessment of a Land Cover Classification
  - Using Google Earth Engine for Land Monitoring Applications



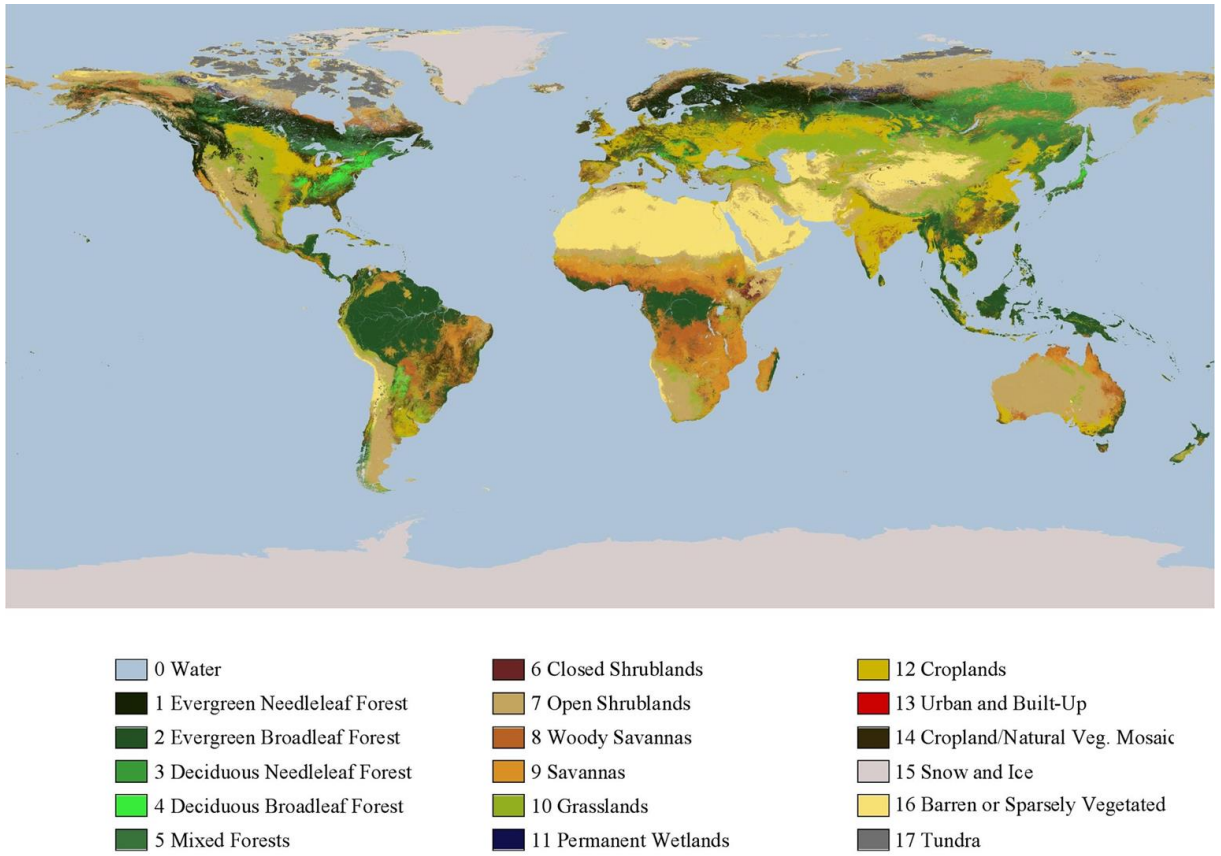
Annual Land Cover. Credit: GEE Developers

Global and Regional Land Cover Maps

MODIS Land Cover

- Contains 5 classification schemes
  - Identifies 17 land cover classes identified by the International Geosphere Biosphere Programme, which includes 11 natural vegetation classes, 3 developed and mosaicked land classes, and 3 non-vegetated land classes
- Spatial Resolution: 500 m
- Temporal Coverage: 2001 – 2019 annually
- Download data from NASA's Earthdata Search: http://search.earthdata.nasa.gov

Global



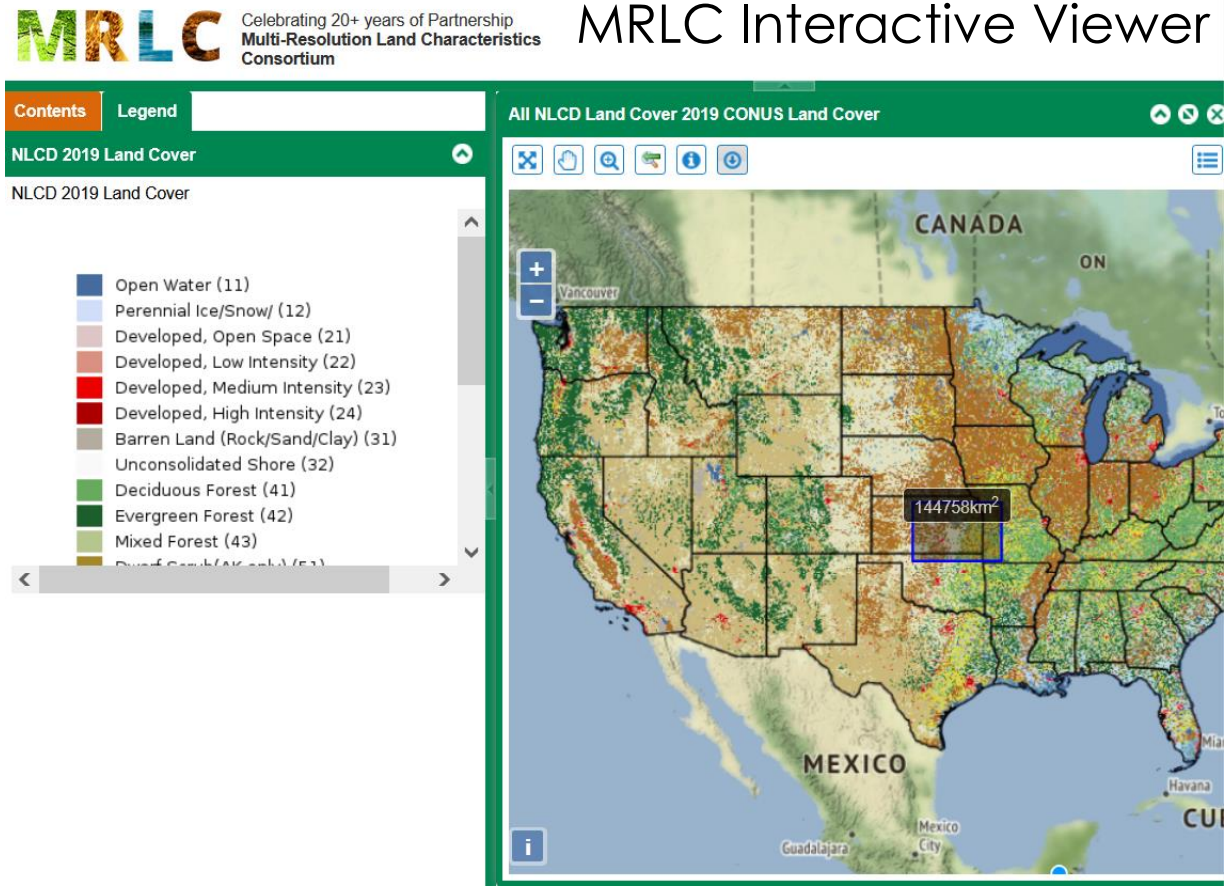
Global and Regional Land Cover Maps

Multi-Resolution Land Characteristics (MRLC) Consortium

- National Land Cover Database (NLCD)
- Landsat-based, 30 m resolution
- 16 land cover classes
- 2001, 2006, 2011, 2013, 2016, 2019
- Other products include:
  - Percent Tree Canopy (2011, 2016)
  - Impervious Descriptor (2001, 2004, 2006, 2008, 2011, 2013, 2016, 2019)
- Multiple interactive viewers for land cover, rangeland metrics, and advanced analysis

United States

MRLC Interactive Viewer



https://www.mrlc.gov

Global and Regional Land Cover Maps

ESA Climate Change Initiative (CCI)

- Global Land Cover Maps (1992 – 2019)
  - Freely register online for data access
- Seasonality Products (NDVI, burned areas)
- Global Water Bodies Product
- https://www.esa-landcover-cci.org/

Image Credit: ESA

Global and Regional Land Cover Maps

Copernicus CORINE Land Cover (CLC)

- European Countries Land Cover Maps for 2000, 2006, 2012, 2018
- Change Maps
- Mapping Units of 25 to 5 Hectares
- Use of Landsat, SPOT, Sentinel-2, etc.
- https://land.copernicus.eu/pan-european/corine-land-cover

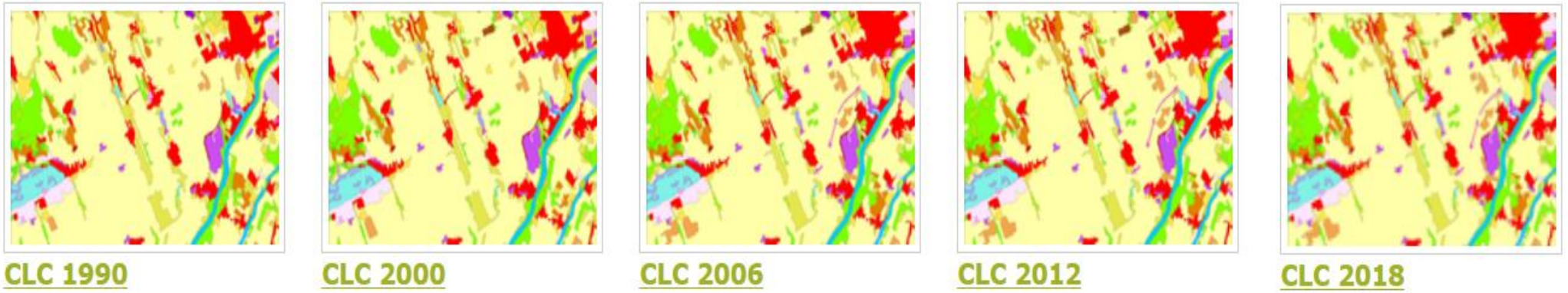


Image Credit: ESA

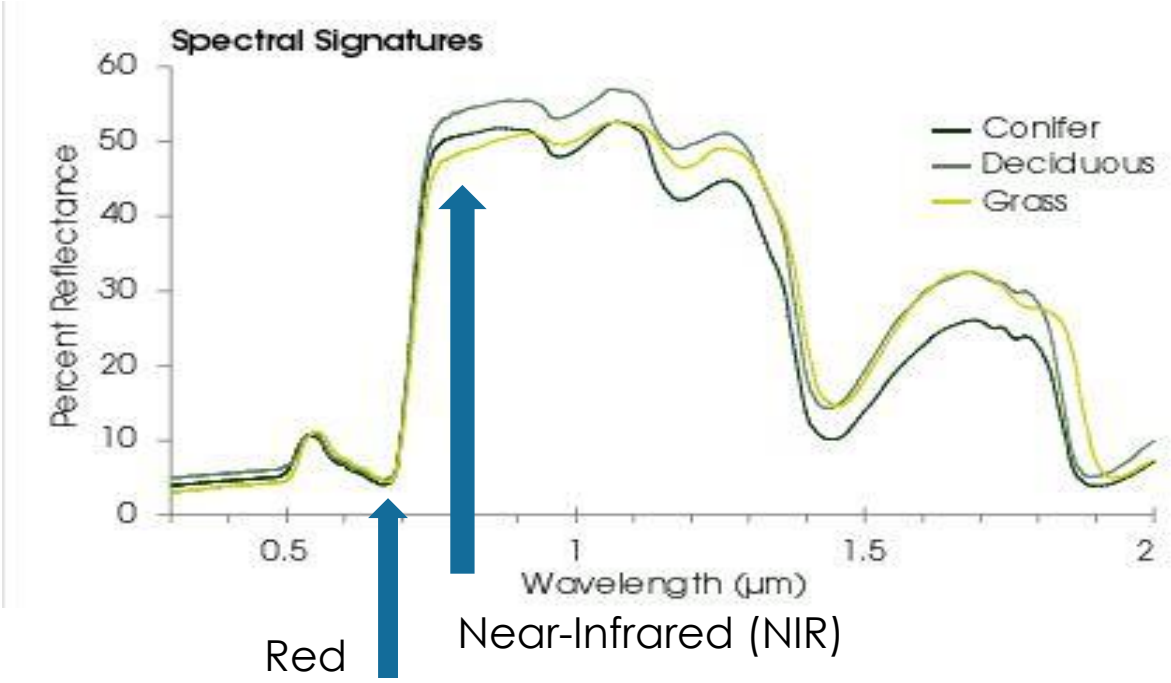
Land Surface Phenology (LSP)

- Use of satellites and sensors to track seasonal patterns in vegetated land surfaces
  - Regular monitoring of the entire global land surface
  - Gather information on entire ecosystems: broad-scale trends
  - Timing of seasonal patterns related to day length, temperature, and precipitation patterns
  - Impacts on species distributions
- Useful when linked to ground observation networks
- See previous NASA ARSET training on phenology: https://appliedsciences.nasa.gov/join-mission/training/english/arset-understanding-phenology-remote-sensing

Seasonal cycle of a tree, Image Credit: USGS/NPN)

Normalized Difference Vegetation Index (NDVI)

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



<u>Near-Infrared – Red</u>

Near-Infrared + Red

- Values range from -1.0 to 1.0
  - Negative values to 0 mean no green leaves.
  - Values close to 1 indicate the highest possible density of green leaves.

Enhanced Vegetation Index (EVI)

$$EVI = G * \left(\frac{(NIR - R)}{(NIR + C1 * R - C2 * B + L)} \right)$$

Constants

$G = 2.5$

$C1 = 6$

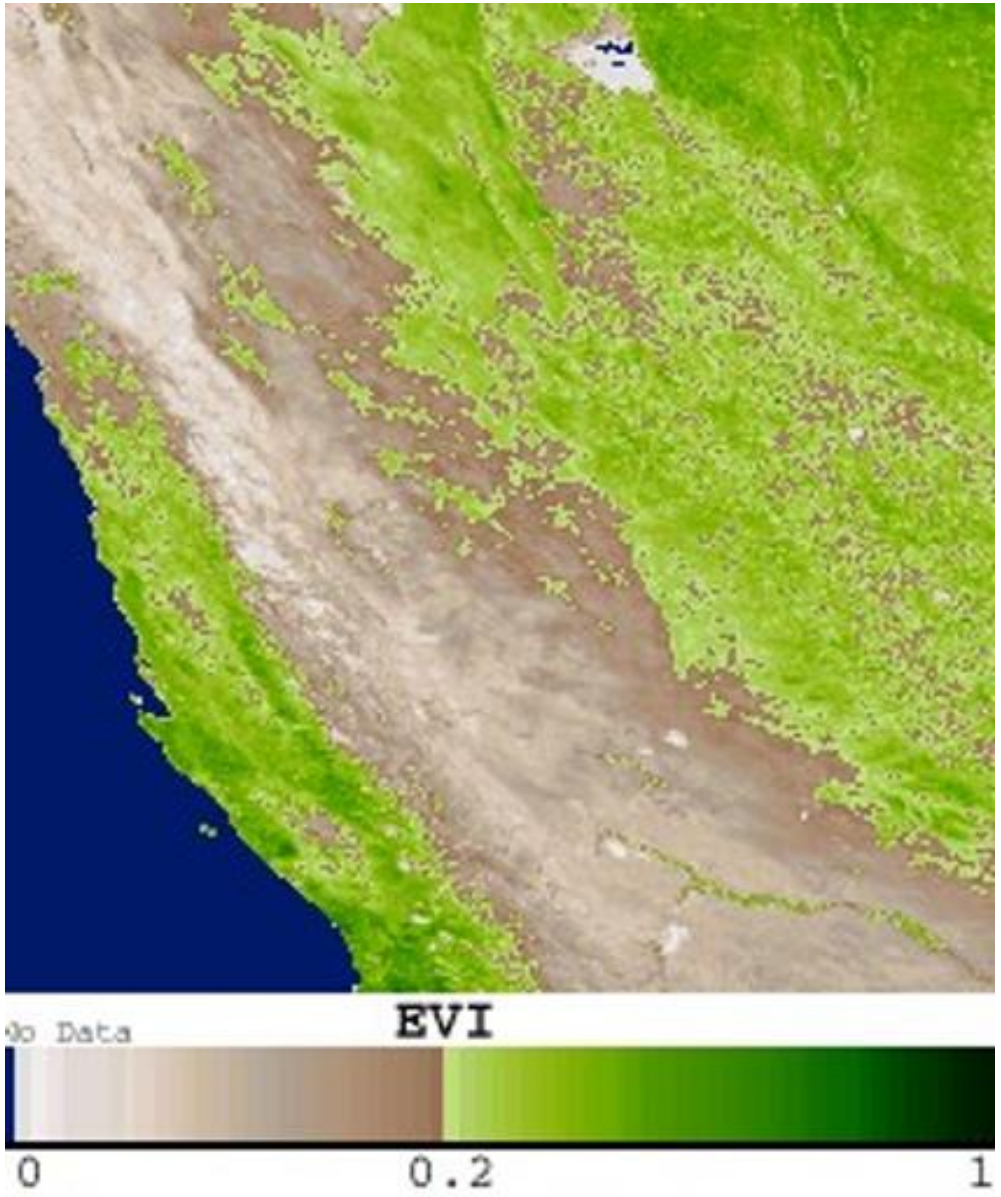
$C2 = 7.5$

$L = 1$

- Does not saturate over high biomass regions
- L = Adjustment for canopy background
- C = Atmospheric adjustment
- Use of the blue band

MODIS NDVI and EVI Products

- 16-day composites
- 250 m, 500 m, and 1 km resolutions
- Retrieved from daily, atmosphere-corrected, bidirectional surface reflectance
- Collection Names: MOD13 (Terra) and MYD13 (Aqua)
  - Multiple subsets based on spatial resolution
- Product available via the Land Processes Distributed Active Archive Center (LP DAAC) tools:
  - AppEEARS
  - Data Pool
  - Earthdata search
  - OPeNDAP

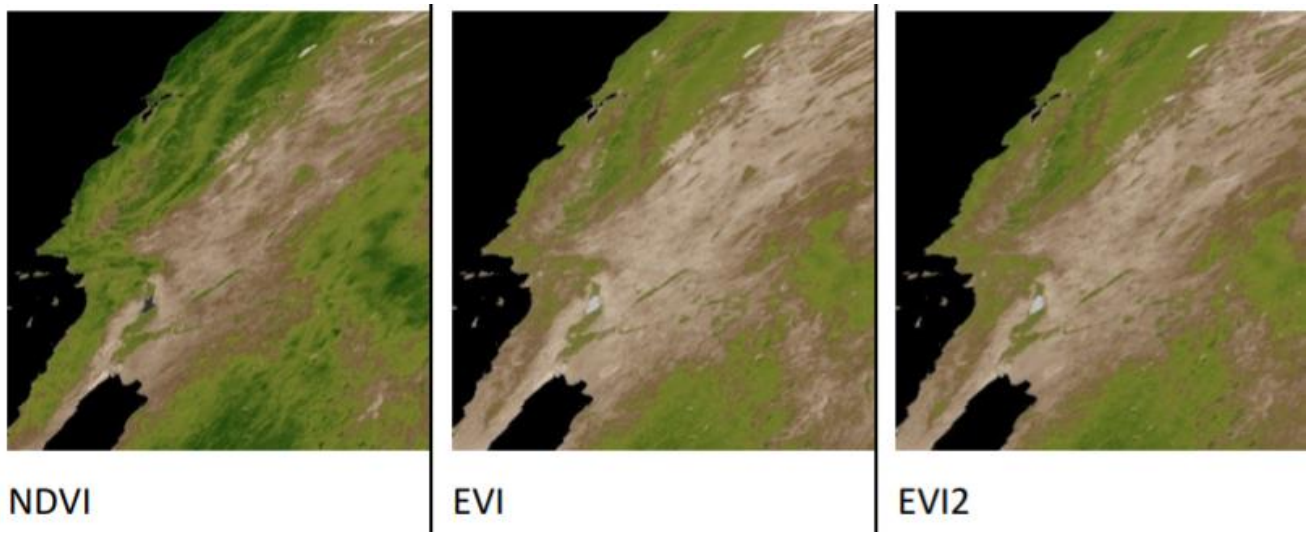


MODIS EVI from April 2020 of the western coast of Africa. Image Credit: USGS/NASA

VIIRS NDVI and EVI Products

- 16-day composites of NDVI, EVI, and EVI2
- 500 m, 1 km ,and 0.05-degree resolutions
- Algorithm selects the best available pixel in a 16-day window

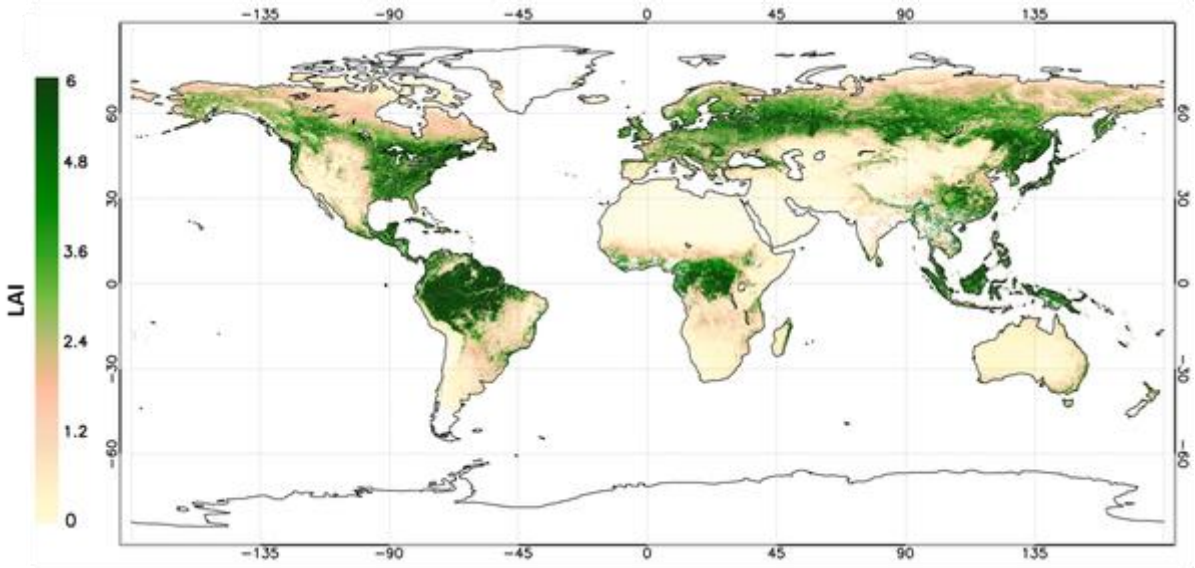
- Collection Name: VNP13
  - Multiple subsets based on spatial resolution
- Product available via the Land Processes Distributed Active Archive Center (LP DAAC) tools:
  - AppEEARS
  - Data Pool
  - Earthdata search
  - OPeNDAP



NDVI, EVI, and EVI2 from VIIRS over western North America Image Credit: USGS/NASA

Leaf Area Index (LAI)

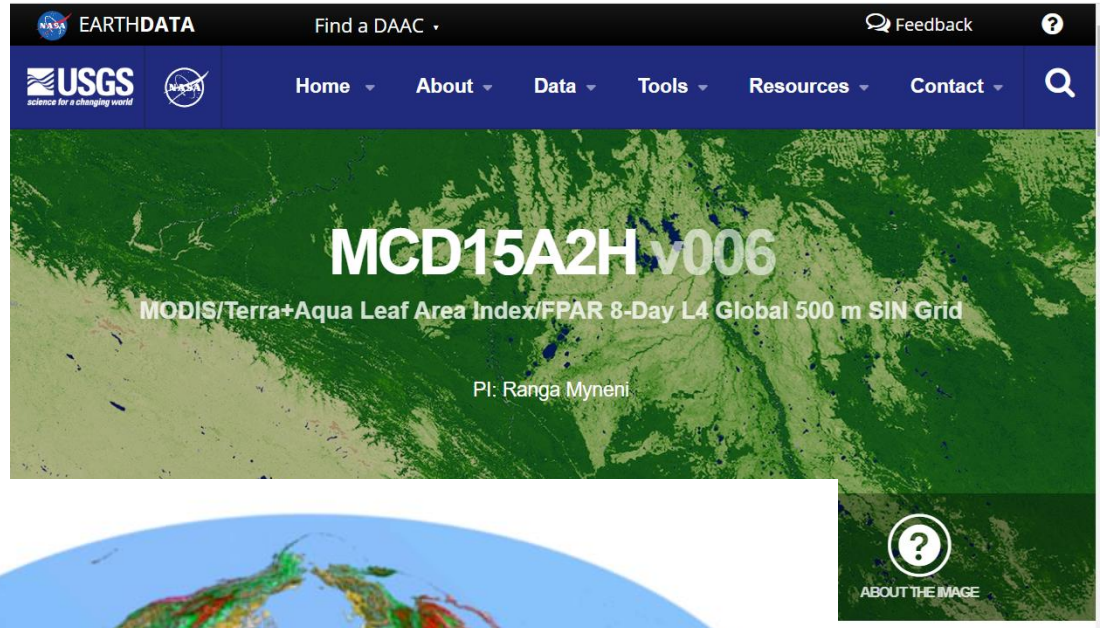
- Ratio of leaf area to per-unit ground surface area
  - Related to photosynthesis, evapotranspiration, rainfall interception, and carbon flux
- Can be calculated based on a regression and spatial relationship between NDVI, EVI, and other vegetation indices
  - Landsat, MODIS, etc.
- Vegetation indices and LAI relationships will not always be linear due to saturation and the complicated structure of the forest canopy.
  - Regression relationships best applied regionally
    - Time- and site-specific

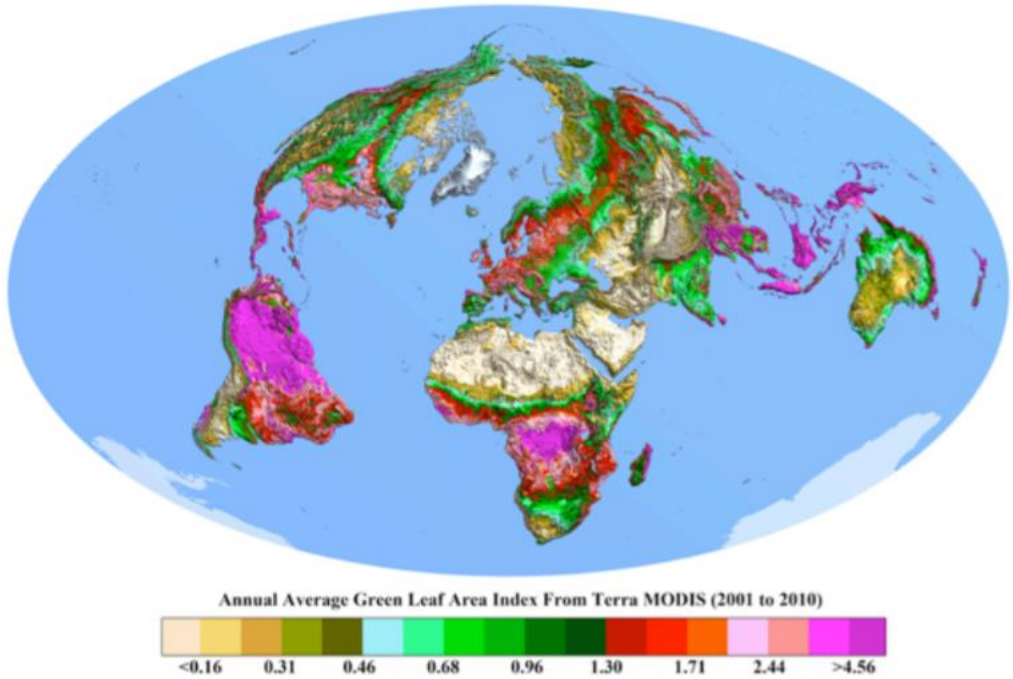


Global LAI from 2017. Image Credit: ESA

MODIS LAI and fPAR Products

- 4-day and 8-day composites
- Spatial Resolution: 500 m
- Collection Names: MCD15A2H (8-day), MCD15A3H (4-day)
- The algorithm chooses the best pixel available from MODIS sensors located on NASA's Terra and Aqua satellites from within the 8-day period.
- Product available via the Land Processes Distributed Active Archive Center (LP DAAC) tools:
  - AppEEARS
  - Data Pool
  - Earthdata search
  - OPeNDAP

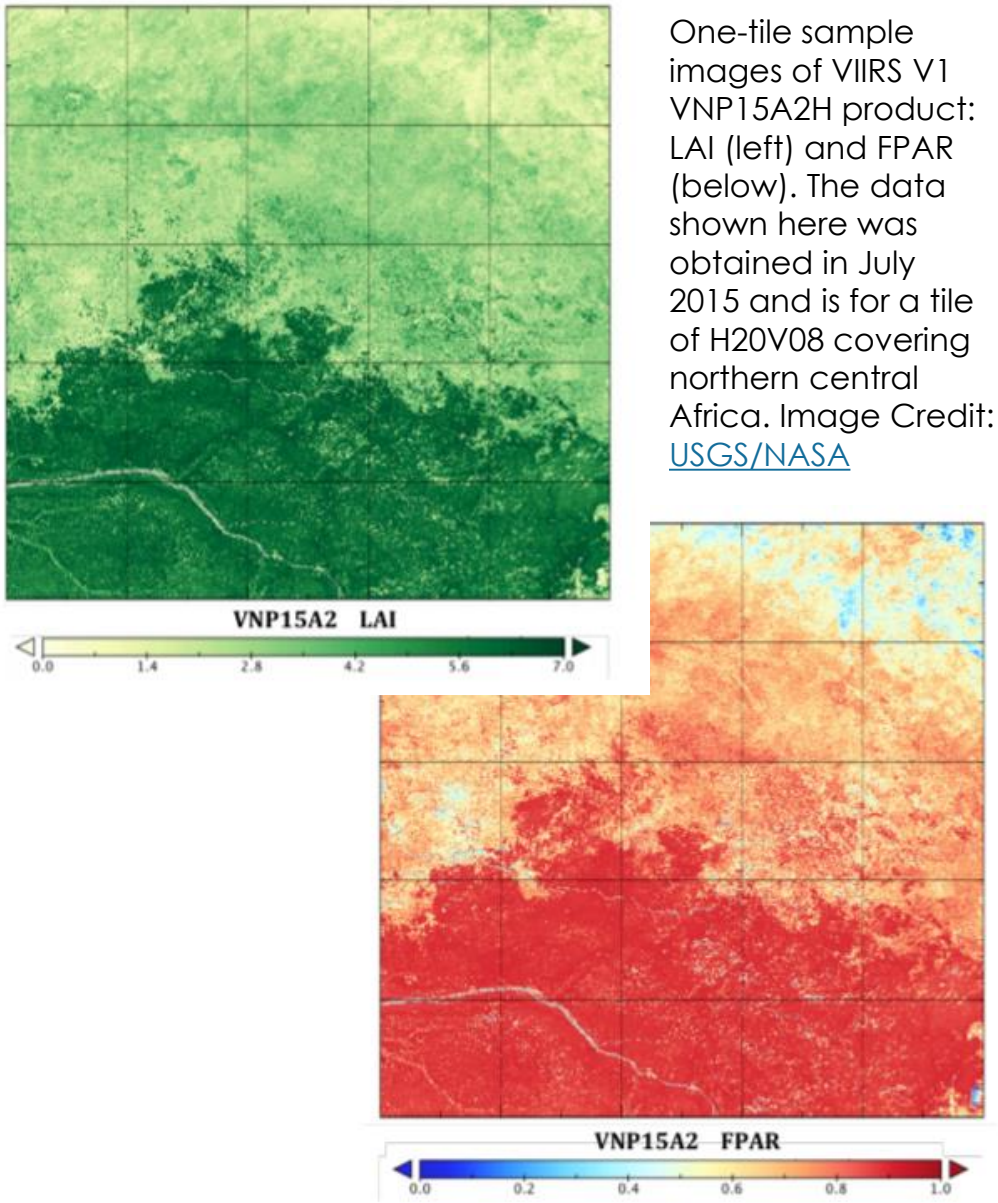




Product Documentation website (above); Global annual average LAI from 2001-2010. Image Credit: USGS/NASA

VIIRS LAI and fPAR Product

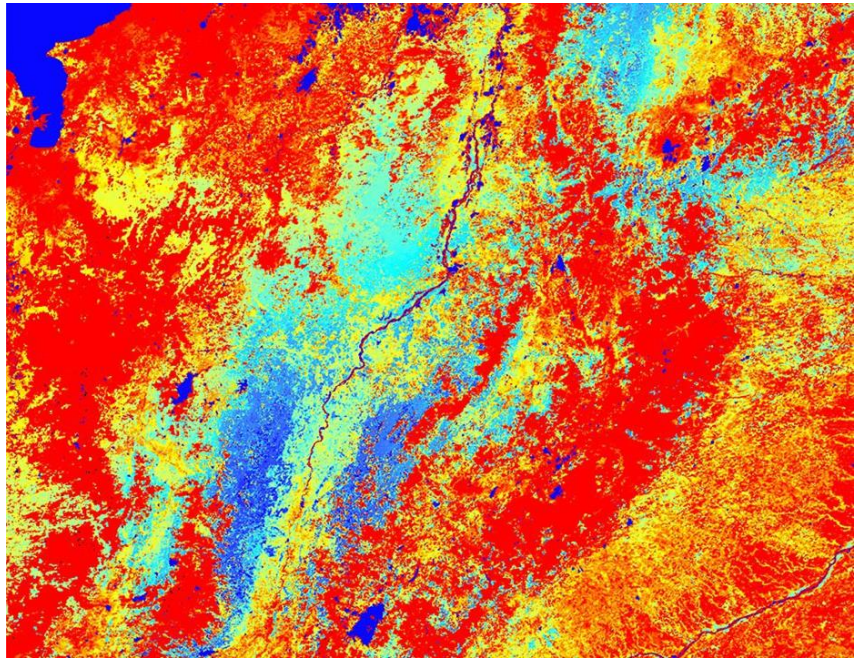
- 8-day composites
- 500 m spatial resolution
- Collection Name: VNP15
- The algorithm chooses the best pixel available from VIIRS from within the 8-day period.
- Product available via the Land Processes Distributed Active Archive Center (LP DAAC) tools:
  - AppEEARS
  - Data Pool
  - Earthdata search
  - OPeNDAP



One-tile sample images of VIIRS V1 VNP15A2H product: LAI (left) and FPAR (below). The data shown here was obtained in July 2015 and is for a tile of H20V08 covering northern central Africa. Image Credit: USGS/NASA

Gross and Net Primary Productivity (GPP and NPP)

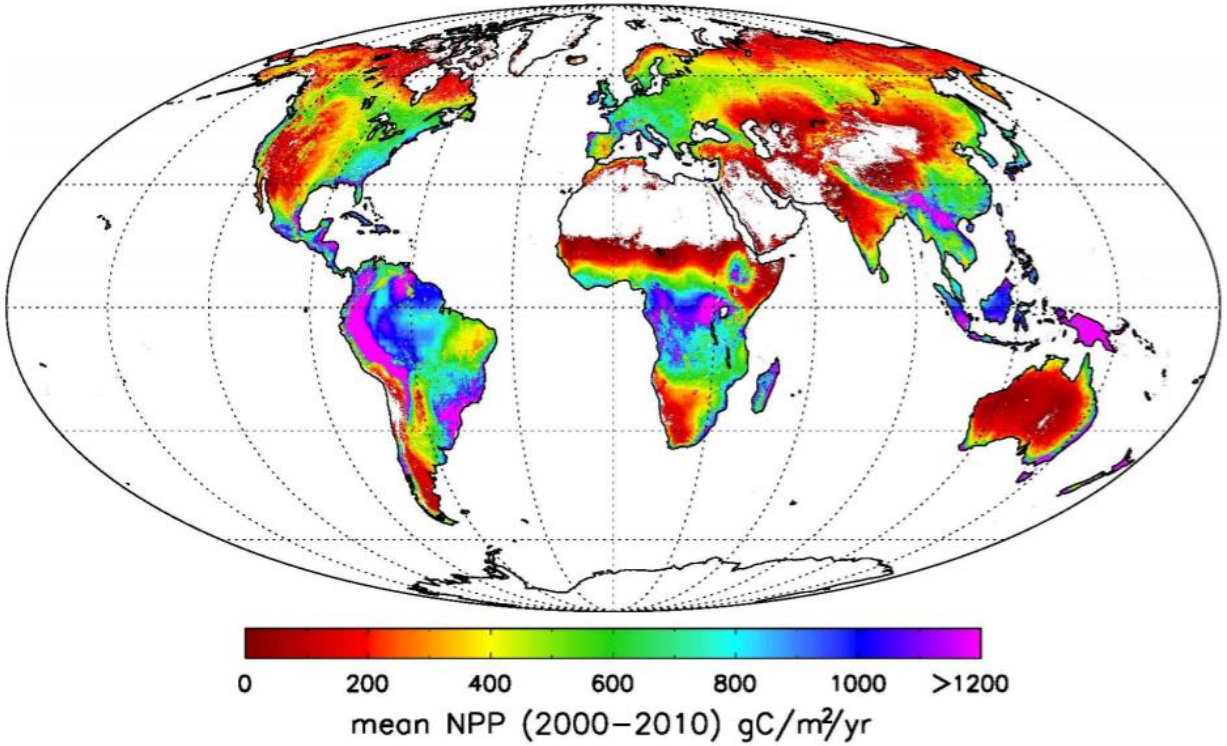
- **GPP**: The overall rate of biomass production by producers.
- **NPP**: Net carbon fixed by vegetation through photosynthesis.
  - GPP – Respiration
  - The carbon required for maintenance of the structure of an ecosystem
- Can be calculated as a product of fPAR and light use (or radiation) efficiency
  - Linear Modeling: Correlates field measurements of fractional cover with NDVI
  - Physical Models: Incorporate parameters related to photosynthesis, evapotranspiration, stress, and decay of plant material
- Also commonly used to monitor ocean chlorophyll



Gross Primary Productivity (GPP) from the MYD17A2H product over central South America on August 29 - September 5, 2018. Image Credit: USGS/NASA

MODIS NPP Product

- Annual
- Spatial Resolution: 500 m
- Collection Name: MCD173HGF
  - New gap-filled version 6
- Derived from the sum of all 8-day Net Photosynthesis (PSN) product (MOD17A2H) from the given year. The PSN value is the difference of the Gross Primary Productivity (GPP) and the Maintenance Respiration (MR).
- Product available via the Land Processes Distributed Active Archive Center (LP DAAC) tools:
  - AppEEARS
  - Data Pool
  - Earthdata search
  - OPeNDAP

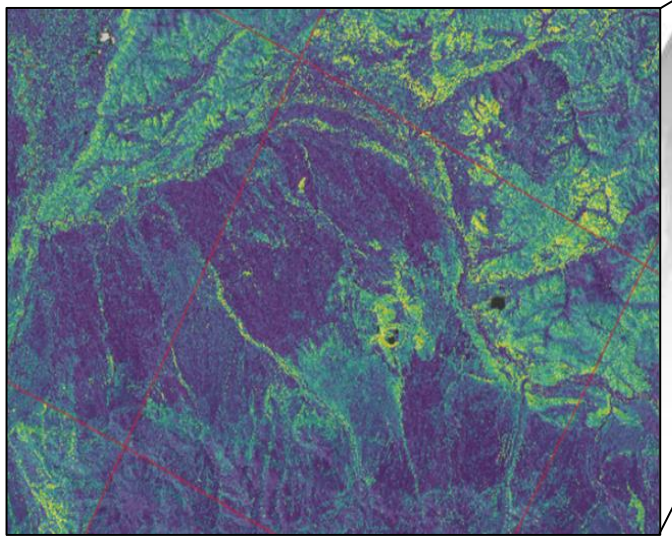


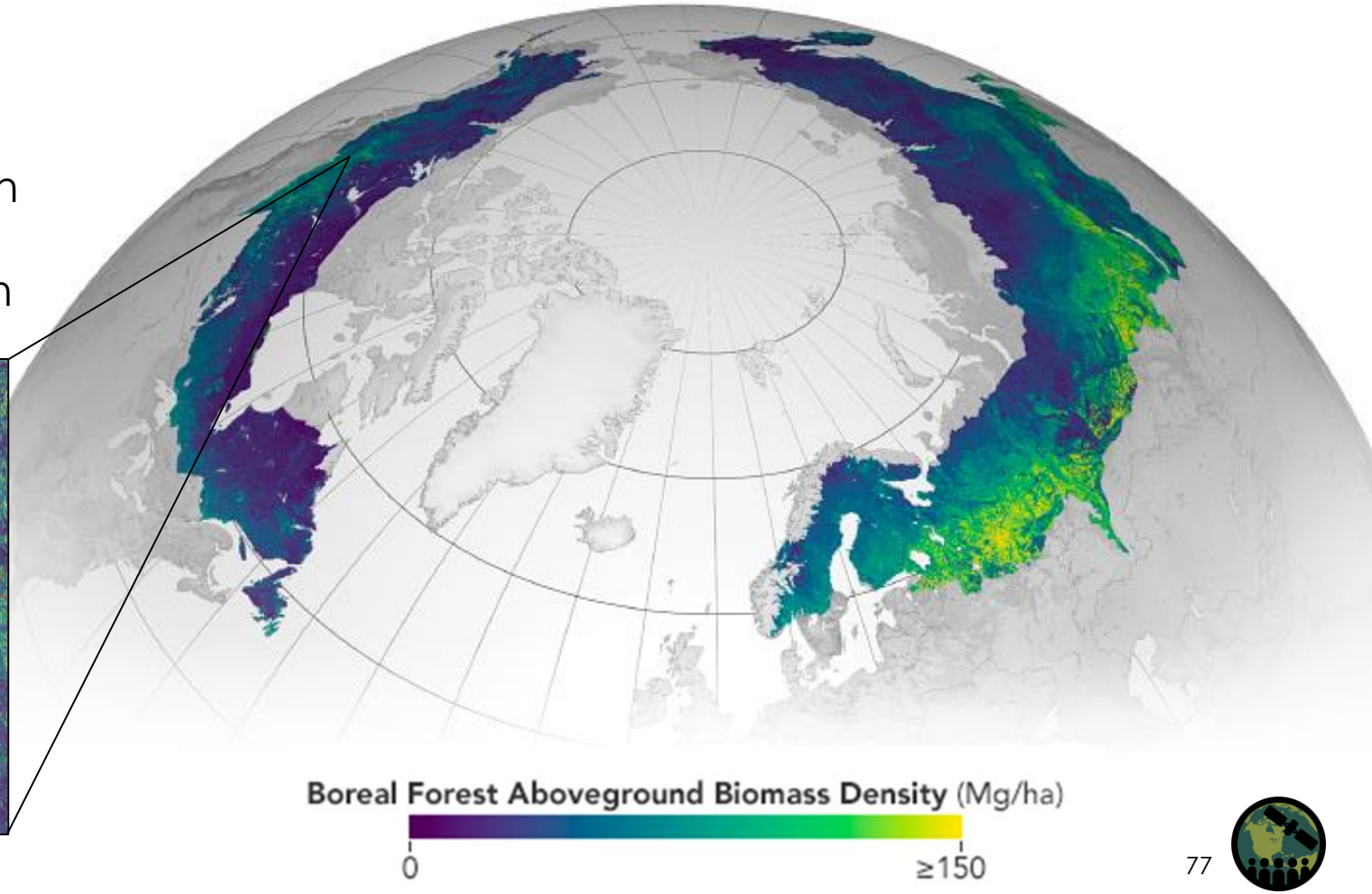
Global average NPP from 2000-2010. Image Credit: USGS/NASA

New Boreal-wide biomass map

- Map uses ICESat-2's vegetation height product in combination with 30 m data from NASA/USGS Landsat 8, and the Copernicus DEM.
- Fills GEDI's Northern data gap for aboveground forest biomass (AGB) mapping for circa 2020.
- Provides insights into how much carbon is currently stored in Arctic and Boreal ecosystems, and how it may change in the future.

Open science product created on the ***NASA-ESA MAAP*** (scimaap.net). Explore this map here: https://earthdata.nasa.gov/maap-biomass





Summary and Connecting the Dots for Next Session

- Ecosystem services are the benefits people obtain from ecosystems.
- Quantifying the value of the ecosystem service benefits is important.
- Many countries are using established frameworks for natural capital accounting.
  - UN System of Environmental-Economic Accounting (SEEA)
- Remote sensing can play a role in environmental economic accounting.
  - Land cover mapping
  - Additional land cover metrics and products
- Next Session:
  - Decision support tools for evaluating ecosystem services
    - The role of remote sensing
  - Overview of ARIES
  - Overview of the Natural Capital Project and InVest

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- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-evaluating-ecosystem-services-remote-sensing

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Thank You!