The NASA Land Cover Land Use Change (LCLUC) Program Activities

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Garik Gutman, LCLUC Program Manager, NASA Headquarter

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International Meeting on Air Pollution in Asia – Inventories, Monitoring and Mitigation, Hanoi, Feb. 2023
LCLUC Silver Jubilee 2022

Foundations
1990 NASA Landsat Pathfinder initiated (UNH, UMD, GSFC)
1990 IGBP-DIS – global data sets (inc. 1km Land Cover)
1994 IGBP/IHDP LUCC officially launched (Skole, Chair)
1996 NASA Created LCLUC Program
1997 First LCLUC Science Team Meeting
LCLUC Program Goals

... FURTHER THE UNDERSTANDING OF THE CONSEQUENCES OF LAND USE CHANGE FOR CONTINUED PROVISION OF ECOLOGICAL GOODS AND SERVICES, SUSTAINABLE LAND MANAGEMENT AND HUMAN WELL BEING

ULTIMATE VISION ... TO DEVELOP THE CAPABILITY TO PERFORM REPEATED INVENTORIES OF LU LC FROM SPACE AND DEVELOP THE SCIENTIFIC UNDERSTANDING AND MODELS NECESSARY TO EVALUATE THE CONSEQUENCES OF OBSERVED CHANGES.

LAND USE IS CENTRAL TO A NUMBER OF ENVIRONMENTAL, SOCIETAL AND POLICY CHALLENGES – CLIMATE CHANGE, SUSTAINABLE DEVELOPMENT, FOOD SECURITY, BIODIVERSITY LOSS
WHERE LCLUC FITS WITHIN NASA

Carbon Cycle and Ecosystems Focus Research Area

- Terrestrial Ecosystems Program
- Ocean Biology Program
- Biodiversity Program
- Applications Program
  - Carbon Management
  - Coastal Management
  - Water Management
  - Agri. Management
- Land-Cover/Land-Use Change Program

Water and Energy Cycle Focus Research Area
- Terrestrial Hydrology

Atmospheric Composition Focus Area
- Radiation Science
LCLUC Program Content

25-yr Program stats:
- >300 projects
  - ~50 ongoing
- >800 researchers
  - >20 post-docs
  - >50 grads
- >1000 publications

Monitoring - 1/3
Impacts - 1/3
Synthesis, other - 1/3

http://lcluc.hq.nasa.gov
The Role of Social Science

- The study of land use requires an interdisciplinary approach combining physical and social sciences
- The Human Dimension has an important role in LCLUC
- Social and Economic science research includes
  - impacts of changes in human behavior policy and economy on LCLUC
  - impacts of Land Use and Cover Change on society
  - mitigation and adaption to climate change of land-use systems
- The Socio-Economic component is often a mandatory part of all LCLUC proposals – unique within NASA
25 Years of External Program Linkages: International

- Global Observations of Forest Cover and Land-use Dynamics (GOFC-GOLD) since 1997
  - Fire Implementation Team office at UMD funded by LCLUC
  - Regional Information Networks coordinated by START

- IGBP/IHDP LUCC → GLP
  - Global Land Program (GLP) forum for international Land Use Science
  - GLP Secretariat is moving to the University of Maryland

- EARSeL (EU Remote Sensing Labs)
  - LULC Special Interest Group
    - Joint biennial workshops

- CEOS/GEO
  - International Working Group on Calibration and Validation
  - Land Surface Imaging (LSI) Constellation Working Group
  - GEO Global Landcover Datasets
  - GEO GEOGLAM Agricultural Monitoring

- Space Agencies
  - ESA
  - VNSC, GISTDA, ISRO, JAXA, PHILSA
  - Worldwide

Ariane de Bremond  Peter Verburg  Francesco Sarti
25 Years of GOFC-GOLD Program Support

"GOFC-GOLD Fellowships for **Data Training** and the Advanced Training Institute on Key GOFC-GOLD Themes", April-May 2012, July-August 2014 Sioux Falls, SD and Boston, MA

- John Townshend
- Tony Janetos
- Chris Justice

LCLUC Support of the Fire IT Office@UMD; @MSU and the Land Cover office @MSU

LCLUC Support of Regional Networks via START

Current GOFC Networks Coordinator, Krishna Vadrevu, NASA MSFC

Former GOFC-GOLD Chair
John Townshend, U. Maryland

St. Petersburg, Russia, 2001

Former GOFC-GOLD Networks Coordinator, Olga Krankina, Oregon State U.

Curtis Woodcock
Boston U.
LCLUC International Regional Initiatives

- **SAFARI (South Africa)**
  - 3-year project, began in August 1999
  - studied the environment of southern Africa
  - LCLUC: burning of African forests & savanna
  - Goal: to explore how emissions affect phenomena ranging from regional crop productivity to global climate change.

- **LBA (Amazon)**
  - Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA): 1998-2006
  - LBA-Eco: Field campaign in several sites to help answering questions on forest conversion, re-growth, selective logging, and the sustainable land use in Amazonia

- **NEESPI (Northern Eurasia)**
  - Currently, Northern Eurasian Future Initiative (NEFI) a regional component of Future Earth

- **MAIRS (Monsoon Asia)**
  - The MAIRS programme (Monsoon Asia Integrated Regional Study) 2006-2016
  - Currently, Monsoon Asia Integrated research for Sustainability - part of Future Earth

- **SARI (South/Southeast Asia)**
  - South/Southeast Asia Research Initiative (SARI) 2014-2024
  - LCLUC interactions on climate, water resources, biodiversity, atmosphere, vulnerability, impacts and adaptation issues
International Regional Science Team Meetings
Last 15 years

- 2007/9: NEESPI/MAIRS
  Urumqi, China

- 2009/1: MAIRS
  Kohn Kaen, Thailand

- 2009/9: MAIRS/NEESPI
  Almaty, Kazakhstan

- 2010/8: NEESPI
  Tartu, Estonia

- 2011/11: MAIRS
  Hanoi, Vietnam

- 2013/11: NEESPI/MAIRS
  Tashkent, Uzbekistan

- 2013/1: MAIRS
  Coimbatore, India

- 2016/1: SARI: Yangon,
  Burma/Myanmar

- 2018/05: Lazon,
  Philippines

- 2019/7: Johor Bahru, Malaysia

- 2022/8: Phnom Penh,
  Cambodia
NEESPI-LCLUC Science
NEESPI: Northern Eurasia Earth Science Partnership Initiative
NEESPI → NEFI (Northern Eurasia Future Initiative)

> 750 scientists from 200 institutions in 30 countries with > 170 projects
80 Ph.D. students
>1500 papers
South/Southeast Asia Research Initiative: SARI
NASA-SARI Science

- LCLUC-2015: South Asia
- LCLUC-2016: Southeast Asia
- LCLUC-2018: All Asia
- LCLUC – 2021 SARI Synthesis

- > 250 scientists
- >150 institutions
- 15 countries
- > 25 projects
- >250 papers
- 12 special issues
25 years of International LCLUC Capacity Building

- Trainings in conjunction with regional LCLUC meetings since 2009
  - NEESPI
  - NASA-ESA Trans-Atlantic Training (TAT) for students in Eastern Europe
  - SARI
  - Pre-TAT LCLUC Training in Latvia - 2010 Czech trainees Premek Stych, Charles U., Prague

- Trainings in South/SE Asia
  - In collaboration with JAXA, GISTDA, VNSC, NIES

Promoting EO-based science, data, products and RS methods

Francesco Sarti, ESA

8 TATs since 2013

Premek Stych, Charles U., Prague

Krishna Vadrevu, NASA MSFC

Students, 2008 Bangkok, Thailand

ARTSA
25 Years of Regional Programs: Summary of Accomplishments

The program has

- advanced scientific analysis to areas of the globe where LCLUC is taking place and provided insight into the various impacts of these changes
- examined the underlying drivers of land-use change including socio-economic, political, institutional aspects in diverse regions of the globe
- evaluated the role of satellite data in initiating projections of future regional land-use change
- built broad networks of international scientists that routinely utilize satellite data to monitor regional land-use change
- fostered international collaboration with regional scientists
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 from NASA to USGS to collect, archive, process, and distribute the image data
- Until 2010 expensive, FREE NOW!
- Two-Landsat system frequency revisit time: 8 days -- in some areas may not provide enough observations for monitoring rapid changes (e.g., Ag) but sufficient for slow changes (e.g., Urban)

The LCLUC Program has been the primary NASA user of Landsat data

BUILDING ON THE LANDSAT LEGACY
Products: Global Mosaic Using Landsat-7 and -5
Products: Tree Cover Extent and Forest Loss and Gain: 2000-2014

Matt Hansen, U. Maryland
Products: Mangroves Extent

Chandra Giri, USGS ➔ EPA
Products: Global cropland extent and change 2000-2020

Potapov et al., Nature Food 2022
The program has

- **provided the basis for monitoring**, reporting and verification of urban-, forest-, and agricultural cover change in the context of the implementation of Carbon Treaties

- **created the means to undertake periodic, continuous global assessments** of Land-Cover and Land-Use Change

- **quantified rapid changes** in the urban built environment, forest cover and agriculture around the globe

- **provided the primary science rationale** for the Landsat Mission and, more general, Sustainable Land Imaging

- **Provided proof of concept for** global Landsat-based products
Landsat Next -- Requirements Meet Emerging Needs

User need surveys provided a clear set of priorities for Landsat Next requirements to meet emerging needs at breakthrough effectiveness:

**Improved Revisit Frequency.** Dynamic phenomena (crop health & productivity, water quality, snow/ice state, wildfire) which require ~weekly clear views.

**Higher Spatial Resolution.** Experience with Sentinel-2 has underscored importance of 10-meter data for monitoring small agricultural fields, forest disturbance, urbanization, and other applications.

**Additional spectral bands** to support emerging applications in water quality, snow hydrology, soil mapping, and other areas.

**Maintaining radiometric quality** established by Landsat 8/9

Landsat Next will provide more than twice as many spectral bands, with resolution improved by a factor of 2, and with the repeat coverage of Landsats 8 and 9, **combined**
RFI Draft SLI “Superspectral” Requirements

- RFI draft “superspectral” spectral bands
  - Included Sentinel-2 bands
  - Added narrow bands for aquatic and cryosphere
  - Shifted SWIR bands for crop residue
  - Shifted/narrowed TIR bands for temperature/emissivity
  - Coastal aerosol at 30m for aquatic and mineral applications

- Radiometric quality intended to match Landsat 8 OLI when aggregated to 30m

<table>
<thead>
<tr>
<th>Band name</th>
<th>Ground Sample Distance (m)</th>
<th>Center wavelength (nm)</th>
<th>Band width (nm)</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Violet</td>
<td>60</td>
<td>410</td>
<td>20</td>
<td>Improved aerosol retrieval; CDOM from inland/coastal water</td>
</tr>
<tr>
<td>2 Coastal Aerosol</td>
<td>30</td>
<td>443</td>
<td>20</td>
<td>Landsat</td>
</tr>
<tr>
<td>3 Blue</td>
<td>10</td>
<td>490</td>
<td>65</td>
<td>Landsat</td>
</tr>
<tr>
<td>4 Green</td>
<td>10</td>
<td>560</td>
<td>35</td>
<td>Landsat</td>
</tr>
<tr>
<td>5 Orange</td>
<td>20</td>
<td>620</td>
<td>20</td>
<td>Phycocyanin detection for Harmful Algal Blooms</td>
</tr>
<tr>
<td>6 Red 1</td>
<td>20</td>
<td>650</td>
<td>20</td>
<td>Phycocyanin, chlorophyll</td>
</tr>
<tr>
<td>7 Red 2</td>
<td>20</td>
<td>665</td>
<td>30</td>
<td>Landsat</td>
</tr>
<tr>
<td>8 Red Edge 1</td>
<td>20</td>
<td>705</td>
<td>15</td>
<td>LAI, Chlorophyll, plant stress (S2)</td>
</tr>
<tr>
<td>9 Red Edge 2</td>
<td>20</td>
<td>740</td>
<td>15</td>
<td>LAI, Chlorophyll, plant stress (S2)</td>
</tr>
<tr>
<td>10 NIR Broad</td>
<td>10</td>
<td>842</td>
<td>115</td>
<td>10m NDVI (S2)</td>
</tr>
<tr>
<td>11 NIR1</td>
<td>20</td>
<td>865</td>
<td>20</td>
<td>Continuity (note – S2 narrower than L8)</td>
</tr>
<tr>
<td>12 Water vapor</td>
<td>60</td>
<td>945</td>
<td>20</td>
<td>Improved atmospheric correction for LST, SR (S2)</td>
</tr>
<tr>
<td>13 Liquid Water</td>
<td>20</td>
<td>985</td>
<td>20</td>
<td>Liquid water, surface water state</td>
</tr>
<tr>
<td>14 Snowlce 1</td>
<td>20</td>
<td>1035</td>
<td>20</td>
<td>Snow grain size for water resources</td>
</tr>
<tr>
<td>15 Snowlce 2</td>
<td>20</td>
<td>1090</td>
<td>20</td>
<td>Ice absorption, snow grain size</td>
</tr>
<tr>
<td>16 Cirrus</td>
<td>60</td>
<td>1375</td>
<td>30</td>
<td>Landsat</td>
</tr>
<tr>
<td>17 SWIR 1</td>
<td>20</td>
<td>1610</td>
<td>90</td>
<td>Landsat</td>
</tr>
<tr>
<td>18 SWIR 2a</td>
<td>20</td>
<td>2100</td>
<td>30</td>
<td>Subdivided for cellulose/crop residue measurement (Landsat)</td>
</tr>
<tr>
<td>19 SWIR 2b</td>
<td>20</td>
<td>2210</td>
<td>40</td>
<td>Subdivided for cellulose/crop residue measurement (Landsat/ASTER)</td>
</tr>
<tr>
<td>20 SWIR 2c</td>
<td>20</td>
<td>2260</td>
<td>40</td>
<td>Subdivided for cellulose/crop residue measurement (Landsat/ASTER)</td>
</tr>
<tr>
<td>21 TIR 1</td>
<td>60</td>
<td>8300</td>
<td>250</td>
<td>Mineral and surface composition mapping (ASTER)</td>
</tr>
<tr>
<td>22 TIR 2</td>
<td>60</td>
<td>8800</td>
<td>350</td>
<td>Emissivity separation, volcanos (SO2) (MODIS/ASTER)</td>
</tr>
<tr>
<td>23 TIR 3</td>
<td>60</td>
<td>9100</td>
<td>350</td>
<td>Mineral and surface composition mapping (ASTER)</td>
</tr>
<tr>
<td>24 TIR 4</td>
<td>60</td>
<td>11300</td>
<td>550</td>
<td>Surface temperature (Landsat), carbonates</td>
</tr>
<tr>
<td>25 TIR 5</td>
<td>60</td>
<td>12000</td>
<td>550</td>
<td>Surface temperature, snow grain size (Landsat)</td>
</tr>
</tbody>
</table>

2020
NASA is increasingly encouraging the use of international satellite data.
HLS - making the combined use of multi-source moderate resolution data easier and more standardized

**HLS Version 1.5 (Global HLS)**

Global processing via NASA MSFC Interagency Implementation and Advanced Concepts Team (IMPACT) cloud computing project

- Forward processing started October 2020
- Back-processing to the beginning of the Landsat 8 and Sentinel-2 data records (2013 and 2015 soon, respectively); Plans to complete in 2023
- ESDIS compliant metadata, user guide, & ATBD
- Cloud Optimized Geotiff (COG) distribution format
- Earth Data interface for search/order GIBS interface for browse
- Unique aspect of HLS: processed, archived, and distributed on Amazon Web Services (AWS) commercial cloud
- Reducing from 2-week processing to 2 days

EDSC: [https://search.earthdata.nasa.gov/search?q=HLS](https://search.earthdata.nasa.gov/search?q=HLS)
Merging Sentinel-2 and Landsat data streams could provide < 5-day coverage required for Agricultural monitoring

- Both sensors have 10-30m coverage in VNIR-SWIR
- Satellite orbits complementary
  - Landsat-8 & -9    8 days
  - Sentinel-2a & 2b  5 days
- Global ~3 day
- Merging in Sentinel-1 radar data provides all-weather microwave observations

Landsat-7
Landsat-8
Landsat-9
Sentinel-2a
Sentinel-2b
Sentinel-1a
Sentinel-1b


Sentinel-2a: launched in Jun 2015
Sentinel-2b: launched in Mar 2017
Sentinel-1a: launched in Apr 2014
Sentinel-1b: launched in Apr 2016
Landsat-7: launched in Apr 1999
Landsat-8: launched in Feb 2013
Landsat-9: launched in Sep 2021

Jeff Masek,
NASA GSFC
MuSLI Project Scientist
Landsat-9 Project Scientist

MuSLI ESA
Project Scientist
Benjamin Koetz,
MuSLI Solicitations: LCLUC-2014 (merging Landsat and Sentinel-2); LCLUC-2017 (incl. Radar data); LCLUC-2020 (incl. VHR data); LCLUC-2023 (incl. IR data and all of the above)
ECOSTRESS: NASA Instrument on ISS

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 ASTER (on TERRA) – more frequent revisits

- 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 CONUS at spatiotemporal scales applicable to improving drought estimation accuracy

Heatwave over Europe: June 2019
Credit: NASA/JPL-Caltech
NASA Global Ecosystem Dynamics Investigation (GEDI) mission

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

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

Global Forest Canopy Height: 2019

Question
What is the carbon balance of the Earth's forests?
How will the land surface mitigate atmospheric CO2 in the future?
How does forest structure affect habitat quality and biodiversity?

Quantify
Forest Biomass
Disturbance and Recovery
Carbon Sequestration Potential
Vertical Forest Structure and its Relationship to Biodiversity

Potapov et al. 2020, RSE
Zooming-in to higher spatial resolutions

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

- The first NASA Data Buy 2003 – Ikonos
- Planet Labs constellation (>200 sats) acquire daily images of the Earth with 3-m resolution
- Maxar (Digital Globe, WorldView) with 1m resolution
- 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)
- Special Issue in Remote Sensing (2020) on applications of VHR data in LCLUC studies
25 Years of Community Outreach
LCLUC@UMD.EDU

- Quarterly e-Newsletter
  - E-Newsletters: 11
- PR, media
- Facebook, twitter, linkedin
- Website
  - Mapper

LCLUC Webinars
- Presentations: 92
- Started in 2014
- Total: 17 series
- Intensified in 2020
- Topical or regional

LCLUC Urban and Agriculture Hotspots Webinar Series - 2022

LCLUC Forest Hotspots Webinar Series - 2022

- Total 21 SARI Webinars.
- Total 1845 individual participants from 117 countries
Objectives for this International Meeting

1). Review GHG and SL Climate Pollutants emission estimates and methodologies from different sources including biomass burning in the Asian region;

2). Understand the impact of GHGs and aerosols on local climate, including health impacts;

3). Explore the potential of satellite remote sensing datasets for quantifying pollutants, aerosols, and pollution episodes;

4). Review modeling approaches for characterizing emissions;

5). Strengthen the regional information exchange and training activities through effective collaborations.
Meeting Sessions

Keynotes (20 mins), Technical (15 mins) + allow 5mins questions

• Day 1:
  – Session I: Inaugural session
  – Session II: Programmatic Presentations
  – Session III: GHG and Pollutant Emission Inventories including Decision Support Systems

• Day 2:
  – Session IV: Land Use and Emissions
  – Session V: Air Pollution Impacts and Health

• Day 3:
  – Session VI: Aerosol Pollution
  – Session VII: Biomass Burning Emissions
  – Discussion Session – Research Needs and Priorities