Summary of the 2019 South/Southeast Asia Research Initiative Land Cover Land Use Change Regional Science Meeting

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Introduction

As a result of growth in South and Southeast Asia (S/SEA), land use/cover change (LUCC) is occurring at a rapid rate, moving from forest to agriculture and from agricultural areas to residential and urban use, with concomitant disruption of water and forest resources, biodiversity, regional climate, biogeochemical cycles, and the atmosphere. To address these issues, NASA's Land Cover/Land Use Change (LCLUC) Program—South/Southeast Asia Research Initiative (SARI, *www.sari.umd.edu*) in collaboration with other partners organized a meeting, titled *Land-Use/Cover Changes, Environment and Emissions in South/Southeast Asia*, held July 22–24, 2019, at the Hilton Hotel in Johor Bahru, Malaysia. The University of Technologi, Malaysia (UTM) hosted the meeting. Collaborators included the National Institute for Environmental Studies (NIES), Japan; the international Global Observations of Forest and Land-Use Dynamics (GOFC–GOLD) program; START,[1] U.S.; and the international Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) initiative, in addition to fourteen other national and international partners. The meeting aimed to review the availability, potential, and limitations of different satellite data sources and methodologies for monitoring LUCC, and its impact on the environment. Another objective was to strengthen GOFC–GOLD S/SEA regional networks on the latest LUCC science.

[1] START (not an acronym) is a core international partner of the U.S. Global Change Research Program that seeks to realize a sustainable future through science (*https://start.org*).

The three-day meeting was attended by 170 participants from 16 countries—see **Photo 1** below.

After several opening presentations, the bulk of the meeting was organized into five sessions, including:

- Updates on Regional Programs and Space Agency Activities;
- Agricultural LUCC;
- Land–Atmosphere Interactions and Emissions;
- Forest LUCC; and
- Urban LUCC.

In addition, on the final day of the meeting there were three discussion sessions that focused on regional research and priorities for agriculture, atmosphere, and LUCC capacity-building themes.

The remainder of this article is organized by day and presents highlights from each of the sessions and the discussions. It also includes a brief description of a press conference held on the afternoon of the first day, to introduce the local media to the practical applications of LUCC science, and a three-day, hands-on training event that took place immediately after the SARI LCLUC meeting, which focused on the use of remote sensing and geographic information systems for LUCC applications. The reader is directed to *https://go.nasa.gov/3a4NtUK* to find more information about the meeting, including the full presentations.

Photo 1. SARI LCLUC regional science meeting participants in Johor Bahru, Malaysia. **Photo credit**: University of Technologi Malaysia (UTM) team

DAY ONE

The first day began with opening remarks to put the meeting in perspective. The remainder of the day was used for a series of presentations from SARI international partners, describing the status of the remote sensing activities of each nation represented—particularly as it relates to LUCC studies. The last two sessions of the day (each with four presentations), on Agricultural LUCC as well as Land–Atmosphere Interactions and Emissions respectively, set up the parallel sessions on each of these topics that would follow on day two. There was also a press conference that took place on the first day—see *The Local Media Learn the Importance of Land Use/Land Cover Science* on page 21.

Opening Remarks

The meeting began with welcoming a series of opening presentations. Speakers included **Kasturi Kanniah** [UTM, Malaysia—*Professor, Built Environment and Surveying*], **Garik Gutman** [NASA Headquarters (HQ)—*LCLUC Program Manager*], **Chris Justice** [University of Maryland, College Park (UMD)—*LCLUC Program Scientist*], **Krishna Vadrevu** [NASA's Marshall Space Flight Center (MSFC)—*SARI Project Lead*], and **Tsuneo Matsunaga** [NIES—*Greenhouse Gases Observing Satellite (GOSAT) Lead*]. All emphasized the need for strengthening international collaboration on LUCC science and building more projects involving U.S. and SARI regional scientists.

Updates on Regional Programs and Space Agency Activities

Garik Gutman presented the latest updates on NASA's LCLUC Program and research activities in S/SEA. He showed that since 2015, more than 25 projects have been funded as a part of the SARI initiative through NASA's LCLUC Program and that the related meetings, workshops, and training activities are strengthening the research and collaborations in S/SEA. He highlighted important LUCC issues in the region, including the loss of agricultural land due to urban expansion, slash-and-burn agriculture impacts on air quality, and the expansion of aquaculture, roads, dams, and mines resulting in the loss of natural habitat. Air quality in several cities of S/SEA is a major concern, as fine particulate matter ($PM_{2.5}$) levels exceed the World Health Organization (WHO) established limits. Further, smoke from slash-and-burn clearing of forests causes transboundary haze that impacts visibility and exacerbates human health concerns in Malaysia, Singapore, and southern Thailand. Satellite instruments from NASA and the European Space Agency (ESA) have been effective tools for following such phenomena, along with a decrease in mangrove forest cover in SEA. Gutman described an increase in such forest cover along the southern coast of Thailand, due to aggradation (deposition from rivers). He stressed the need for strong collaborations in research capacity building and training activities in SARI countries.

Prakash Chauhan [Indian Institute of Remote Sensing (IIRS)] highlighted the operational remote sensing satellite missions of the Indian Space Research Organization (ISRO), along with some of their technical characteristics, emphasizing improvements and overlaps. Chauhan mentioned that most of the data from ISRO missions are useful for planning, monitoring, evaluating, and providing decision support in LUCC. Satellite-based weather and ocean data are available from ISRO's Meteorological & Oceanographic Satellite Data Archival Centre (MOSDAC; *https://www.mosdac.gov.in*), while the land-based data are available from ISRO's Geo-Platform—called *Bhuvan*.[2] Chauhan also mentioned that the IIRS is involved in training and education programs.

Lam Dao Nguyen [Vietnam National Space Center (VNSC)] provided details on the ongoing space activities in Vietnam. He stated that data from the Vietnam Natural Resources, Environment and Disaster Monitoring Satellite (VNREDSat-1), launched in 2013, are used for forest mapping, land, urban, and water management studies. Also, VNSC has been using ESA's Copernicus Sentinel-1 and Canadian RADARSAT (1995–2013) data for forest cover observations and for rice mapping and monitoring, including flood detection, in Vietnam. In addition, under the Committee for Earth Observations (CEOS) activities, a data cube is being developed integrating data from several NASA and ESA platforms for forest and rice monitoring studies.

Rokhis Khomarudin [National Institute of Aeronautics and Space,[3] Indonesia] presented updates on the LAPAN space remote sensing activities, noting the ongoing success of the LAPAN-A3 satellite, which was launched in June 2016 to be used for LUCC studies. The LAPAN project also receives data from many NASA and ESA satellites through their ground stations. These datasets are routinely used for mapping forest cover, mining activities, industrial areas, and paddy-growth monitoring.

Gay Perez [University of the Philippines] provided details on Philippine space remote sensing activities. Two important satellites currently on orbit include DIWATA-1 (D-1) and DIWATA-2 (D-2).[4] D-1 was launched in April 2016 and D-2 in October 2018. D-1 already exceeded its estimated lifespan of 18

[2] Bhuvan is a web-based utility which allows users to explore a set of map-based content prepared by the Indian Space Research Organisation. It can be accessed at *https://bhuvan.nrsc.gov.in/bhuvan_links.php*.

[3] In Malaysian, this is Lembaga Penerbangan dan Antariksa Nasional (LAPAN).

[4] This is not an acronym: In Philippine mythology, a *Diwata* is a type of deity or spirit. The platform is also called PHL Microsat-1.

months whereas the D-2 estimated lifespan is 3-5 years. Both these satellites have a high-precision telescope, a spaceborne multispectral imager, and an enhanced-resolution camera. D-1 and D-2 have already captured just over a third of the Philippine land area and the data are mostly used for vegetation change assessment, post-typhoon damage assessment, monitoring built-up areas, and delineating landslides. Perez noted that the Philippine Senate has already approved the *Philippine Space Act,* signed into law August 13, 2019, paving the way for the formation of the Philippines Space Agency.

Noordin Ahmad [Malaysian National Space Agency—*Former Director General*] reported that in February 2019 the Malaysian Cabinet approved the merger of two agencies: the National Space Agency and the Malaysian Remote Sensing Agency. Several remote sensing projects are ongoing at the agency, e.g., forest mapping and monitoring, disaster management, and urban infrastructure mapping and monitoring.

The remainder of the first day included four presentations each on Agricultural LUCC and Land–Atmosphere Interactions and Emissions. Then on the second day, there were full-day parallel sessions on both these topics.

DAY TWO

Having introduced these two topics in the final presentations on the first day, the second day was dedicated to full-day parallel sessions on Agricultural LUCC and Land-Atmosphere Interactions and Emissions.

Agricultural LUCC

The agriculture session included the following parallel sessions: Agricultural LUCC and Geoinformatics; Rice Mapping and Monitoring in Asia; Modeling and Decision Support Systems; and a Panel Discussion on Agricultural Research Needs and Priorities. The highlights of the discussion are summarized here.

The GEOGLAM initiative was developed by GEO, which is a partnership of governments and international organizations, hosted at the World Meteorological Organization (WMO) in Geneva. The role of

The Local Media Learn the Importance of Land Use/Cover Change Science

A press conference was organized involving local reporters and meeting organizers from the UTM, NASA, NIES, and the University of Illinois Urbana–Champaign—see **Photo**, below. The organizers explained the significance of the meeting and why addressing LUCC is important in S/SEA countries considering rapid deforestation, conversion of agriculture to urban areas, and increased pollution due to biomass burning and motor vehicles in the region. Also, the organizers emphasized the importance of satellite remote sensing and Earth observations in addressing environmental problems in developing countries and the need to educate regional researchers through sharing data and training on how to use them.

A press conference held during the first day of the SARI LCLUC meeting provided an opportunity for meeting organizers to promote the importance of LUCC science to the local media in Malaysia. Pictured here are [*left to right*]: **Toshimasa Ohara** [NIES], **Kasturi Kanniah, Mohd Hamdan Ahmad** [University of Technologi Malaysia (UTM)—*Dean, Faculty of Built Environment*], **Wahid Omar** [UTM—*Vice Chancellor*], **Garik Gutman**, **Krishna Vadrevu**, **Chris Justice**, **Tsuneo Matsunaga**, and **Atul Jain** [University of Illinois Urbana-Champaign]. **Photo Credit**: UTM team

GEOGLAM is to coordinate satellite monitoring observation systems in different regions of the world to enhance crop production projections and weather forecasting data. Within this framework, starting in 2013 GEOGLAM developed the Crop Monitor reports of the Agricultural Market Information Systems (AMIS), which provide global consensus crop condition assessments. Given the success of the AMIS Crop Monitor, GEOGLAM developed the Early Warning Crop Monitor, which began in 2016 and focused on developing a consensus on crop conditions from international, regional, and national organizations for countries at risk of food insecurity.[5]

Monitoring Agricultural Changes for Profitability

In India, LUCC crop mapping using multitemporal data from the Advanced Wide Field Sensor on the Indian Remote Sensing Satellite is now complete. Sown areas for summer and winter crops and other LUCC information are provided on an annual basis. The data can be downloaded from *http://bhuvan.nrsc.gov.in/gis/thematic/index.php#*.

Agriculture accounts for 12% of the national gross domestic product (GDP) in Malaysia and employs 16% of the population. Palm oil, rubber, cocoa, and rice are the major crops. Malaysia currently accounts for 39% of the world's palm-oil production and 44% of the world's palm-oil exports. Large-scale palm-oil monitoring (e.g., using Landsat) is well established and successful; however, the main challenge is to identify individual disease/infection levels for oil palms. In contrast, rubber mapping in Malaysia is not done—because it is difficult to differentiate rubber from other green trees including young and mature rubber trees.

In Dong Thap and An Giang provinces of Vietnam, very high-resolution Planetscope data from 2010 to 2019 showed that rice paddies are being converted to other vegetation types (e.g., bamboo, melons, corn) as they are more profitable. Similar changes to those described for Malaysia were observed in the Red River Delta of Vietnam, where crop diversification is ongoing. In the Mekong Region, preliminary results suggest that existing dams do not have a major impact on river-flow dynamics, however, the impact of flow in tributaries could be significant depending on dam location.

Monitoring Agricultural Changes from Natural Phenomena

In the Philippines, El Niño-induced droughts had a significant impact on the reduction of corn production during 1997–1998, 2009–2010, and 2015–2016. Drought indices such as the Standardized Precipitation Index (SPI)[6] from the Tropical Rainfall Measuring Mission (TRMM) and other indices from MODIS[7] (e.g., Standardized Vegetation Temperature Ratio, Vegetation Health Index) and SPI-3 were congruent in terms of drought progression; however, these indices were weakly correlated with satellite retrieved soil moisture data from the Soil Moisture Active Passive (SMAP) satellite. Thus, a combination of satellite and ground-based measurements was recommended to address droughts. In the Indian states of Punjab and Haryana, wheat yield forecasting was done by combining MODIS vegetation indices using TIMESAT software,[8] which provided phenological parameters for 2009–2010 with reasonable prediction strength. Also, a crop-simulation model titled InfoCrop, a user-friendly crop modeling system, was used for crop-yield simulation for subsequent years, with very low error in Punjab and Haryana.

Radar-Based Studies for Crop Management

Some presentations in this session stressed the need to use synthetic aperture radar (SAR) data to map and monitor crops—due to persistent cloud cover in S/SEA that prevents other data acquisition techniques from being utilized. At the Philippines' International Rice Research Institute (IRRI), multitemporal Sentinel-1 SAR data are being used to routinely map rice in S/SEA countries and also to create in-season and end-of-season rice-yield forecasts. Also, SAR data have been used to map droughts in Thailand, India, and Cambodia. Sentinel-1 data were used to map inundation from Cyclone Titli, which occurred in October 2018, in Andhra Pradesh, India—damaging 26% of the estimated rice paddy. Meanwhile, in Malaysia, geospatial technology is being used for agricultural land-use mapping, soil surveys, precision farming, and yield forecasting. Specifically, RADARSAT data are being used to monitor crop management including land preparation, irrigation, planting, and harvesting. Sentinel-1 is effective for mapping rice paddy in cloud-prone tropical areas in monsoon Asia with double or multiple cropping systems. Other presentations showed results from Indonesia, which are similar to those obtained in Malaysia. Before 2013, only MODIS and Landsat data were used to track rice paddy dynamics, however, the Support Vector Machine approach—with an overall accuracy of greater than 95%—has been used to map paddy fields for 2018.

[5] To learn more about this topic, see "Increasing Information Access for Food Security Monitoring: Overview of the GEOGLAM Crop Monitor for Early Warning (CM4EW)" in the May–June 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 3**, pp. 4–14—*https://go.nasa.gov/2U661yF*].

[6] SPI stands for Standardized Precipitation Index, and is produced by the Copernicus European Drought Observatory (EDO). The "SPI-3" is computed for a three-month accumulation period.

[7] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platforms.

[8] TIMESAT is a software package for analyzing time series of satellite data (*http://web.nateko.lu.se/timesat/timesat.asp*).

Panel Discussion Summary

Chris Justice [*GEOGLAM Co-Chair and NASA Harvest Chief Scientist*] led a panel discussion with GEOGLAM researchers from each country identifying national priorities and "gaps" in agricultural monitoring. National priorities included the need for increased use of remote sensing in national crop-monitoring systems; support in moving research into the operational domain and the adoption of satellite-based monitoring and crop forecasting by operational agencies; developing incentives for *in situ* data sharing; and standardizing drought-monitoring. The gaps identified included the need to: build geospatial capacity in government and local agencies; expedite adoption of new technology by farmers and extension services; improve field-level monitoring for rapid and robust crop insurance claim settlements; establish remote sensing to monitor policy compliance and adoption by farmers; and standardize satellite methods and products. Reiterated throughout the discussions was the need for focused, regional workshops to share technical expertise and methods to monitor crops between countries as well as standardizing methods, products, and best practices. One reason there is such need to standardize methods within the community is that there has been a rapid proliferation of different techniques for rice mapping and monitoring in recent years, and the products resulting from each are not easily compared.

Land–Atmosphere Interactions and Emissions

The atmospheric parallel session included discussion of emission inventories and modeling of pollutants and biomass burning, including aerosols. There was also a panel discussion on atmospheric research needs and priorities. Thematic summaries are provided here.

Satellite Sources of Relevant Data

Presentations during this session included details on several satellites useful for emissions and fire monitoring. The GOSAT-1 and GOSAT-2 missions, launched in 2009 and 2018 respectively, have been providing columnar measurements of carbon dioxide (CO_2), methane (CH_4), and water vapor (H_2O), useful for climate change studies. In addition, GOSAT-2 provides chlorophyll fluorescence and a proxy-methane product. The GOSAT-2 products will be released through the NIES website.

The Visible Infrared Imaging Radiometer Suite (VIIRS) launched on the Suomi National Polar-orbiting Platform (NPP) [2011] and National Oceanic and Atmospheric Administration-20 (NOAA-20)[9] [2017] satellites, has 22 bands with global coverage every 12 hours. Data from the VIIRS M-band [750-m (2460-ft) resolution] and I-band [375-m (1230-ft) resolution] are useful for monitoring fires; M-bands 7–11 are particularly good for detecting combustion sources. VIIRS also has a low-light, nighttime imaging capability: the VIIRS Day-Night Band detects electric lighting, fires, and flares—down to the level of street lamps. The VIIRS nighttime products are available from *https://go.nasa.gov/2wKMVFr*.[10]

The Geostationary Operational Environmental Satellite–R (GOES-R) series, which currently includes GOES-16 [a.k.a., GOES-East, launched November 2016] and GOES-17 [a.k.a., GOES-West, launched March 2018],[11] carry the Advanced Baseline Imager (ABI) with 16 spectral bands and full-disk capture every 10 minutes, which provide additional fire detection and characterization capability using Band 7 [3.9 μm] data.

Specific to atmospheric correction, an algorithm titled Land Surface Reflectance Code (LaSRC), for correcting sensor measurements made at all resolutions: i.e., from coarse- to high-resolution for atmospheric effects, is available freely from **Eric Vermote** [GSFC] *ateric.f.vermote@nasa.gov*.

Greenhouse Gas Emissions and Other Pollutants from Human Activity

Other presentations focused on greenhouse gas (GHG) emissions. The historical emissions inventory for 1960–2015 for S/SEA, titled Regional Emission inventory in ASia (REAS), has been updated from Version 2.1 to Version 3.0. The monthly emissions inventory data cover sulfur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), nonmethane volatile organic compounds (NMVOC), particulate matter (both $PM_{2.5}$ and PM_{10}), black carbon (BC), organic carbon (OC), ammonia (NH_3), and CO_2. Emissions of all air pollutants in Asia increased significantly between 1950 and 2015; in particular, the largest contributor to emissions of NO_x in SEA is Indonesia, followed by Thailand, Philippines, Vietnam, and Malaysia.

Specific to the GHG emissions from food production, CH_4 is the most important greenhouse gas emitted from the rice paddies in S/SEA, with India and Indonesia being the highest emitters. Results from one of the Stability of Altered Forest Ecosystems (SAFE) site in

[9] NOAA-20 was formerly known as Joint Polar Satellite System–1 (JPSS-1). Three more JPSS missions are planned over the coming decade.

[10] To learn much more about applications for VIIRS DNB observations and other observations of our home planet after the Sun goes down, see *The Earth at Night*, which can be downloaded as an eBook or PDF from *https://www.nasa.gov/connect/ebooks/earthatnight_detail.html*.

[11] Two more GOES-R satellites (GOES-T and -U) are planned for launch in 2021 and 2024, respectively.

Sabah [Borneo, Indonesia] suggests that riparian strips are efficient in CH_4 uptake, however, they can also be a source for nitrous oxide (N_2O) and CO_2 emissions.

In the Philippines for 2013 there was one motor vehicle for every 12 people. Motor vehicle exhaust produces tiny airborne particulate matter and other pollutants that are hazardous to health; thus, addressing air pollution from mobile sources is one of the major concerns in the Philippines. In Southern Thailand, both motor vehicle emissions and biomass burning dominate over other sources. Ambient particles smaller than 100 nm ($PM_{0.1}$) dominate the aerosol particles. In East Asia (EA), 11 countries participate in a nanoparticle monitoring network titled EA-nanonet, which provides monthly measurements.

Atmospheric Effects from Natural and Human-Caused Fires

Vegetation fires in S/SEA are a recurrent problem. Trends in vegetation fires using data from MODIS [2003–2016] and VIIRS [2012–2016] suggest increasing numbers of fires in India, Cambodia, and Vietnam. In South Asia, agricultural fires dominate in India, Pakistan, and Sri Lanka, whereas the fires are mostly natural (i.e., forest-related) in Nepal and Bhutan. In SEA, Thailand, Timor Leste, and the Philippines, agricultural fires are the dominant source; conversely, in Malaysia, Cambodia, Brunei, and Myanmar, forest fires are dominant. Also, fires show a strong negative correlation with precipitation, which acts as a fire suppressor. In Indonesia, the provinces of Riau and Jambi are hotspots of peatland biomass burning—where aerosol optical depths above 5.0 have been observed. In the peatlands, the depth of the water table determines the amount of peat that can burn, i.e., most of the fires occur on surfaces where the ground water level (GWL) is below 20 cm (7.9 in). In degraded peatlands, GWL has less influence. In Chiang Mai, Thailand, BC and brown carbon (BrC) emissions from fires can affect planetary boundary layer (PBL) development the next day, producing high and persistent air pollution. To address the PBL dynamics, ground-based measurements such as lidar are quite useful.

In Malaysia, 65 continuous automatic air quality monitoring stations from the Department of Environment measure $PM_{2.5}$, PM_{10}, and other gases such as SO_2, NO_X, CO, CH_4, ozone (O_3), and non-methane hydrocarbons (NMHCs). In addition, they measure meteorological parameters from industrial, residential, traffic, and rural areas. Further, 14 stations from the meteorological department measure total suspended particles and nine stations measure PM_{10}. Additionally, three AErosol RObotic NETwork (AERONET) stations measure aerosols (*http://aeronet.gsfc.nasa.gov*). There is a strong need to address aerosol impacts on radiative forcing and to address particulate matter pollution impacts on health in Malaysia.

An air pollution mitigation study using the Asian-Pacific Integrated Model (AIM) model suggested several measures to curb pollution in S/SEA, e.g., use of end-of-pipe mitigation measures (achieved through improving fuel quality, such as by shifting to fuels with lower sulfur content); improving energy efficiency through high-energy efficient technologies; and through drastic energy shift, e.g., from coal to renewables or natural gas.

Panel Discussion Summary

Tsuneo Matsunaga led the atmospheric research needs and priorities panel discussion. The panel included representatives from Malaysia, Vietnam, Indonesia, Philippines, Thailand, Japan, China, and Singapore. All researchers highlighted the need for more atmospheric research projects in S/SEA. The various panelists identified potential solutions to reduce air pollution in the region, which included targeting the energy sector to reduce emissions, biomass burning, transportation, and adopting low carbon strategies, e.g., introducing more public transportation options. Participants also identified the need to develop integrated emission inventories to mitigate pollution, including more funding for monitoring stations. On translating the research to operations, panel members felt the need to develop integrated assessment systems to map and monitor pollution regularly in different countries. Citizen science and linking pollution to human health were also suggested as important topics of priority. All participants highlighted the need for more training activities in the region.

DAY THREE

The third day included sessions on forest and urban LUCC. The meeting ended with a plenary discussion, which included a regional science summary and overview of research and capacity-building priorities in SARI countries. The fifteen presentations that were delivered on the final day of the meeting showcased the latest remote sensing approaches for forest and urban mapping and monitoring in the region.

Forest LUCC

In SEA, Myanmar, Laos, and Cambodia approximately 44,000 km^2 (17,000 mi^2) of rubber has been planted between 2003 and 2014. Of that amount, 50% has been planted on former evergreen forest lands, 18% on deciduous forest land, and 32% on low-vegetation areas; a significant amount of rubber plantation expansion took place in that time period. In these

countries, rubber expansion is mainly attributed to governmental policies that promoted foreign investments in the industrial plantations as a win–win solution to alleviate poverty in remote rural areas. However, the recent 2019 and 2020 forecast for rubber prices suggests a significant decline, which could reduce rubber expansion and lead to replacement in the future.

In Malaysia during 2018, the Forest Research Institute (FRI) experimented with using both airborne lidar and drones equipped with red–green–blue (RGB) cameras to estimate forest above-ground biomass (AGB) and for forest mapping in some project areas. The results seem promising and the FRI plans to extend the approach to larger regions. Analysis of data obtained between 2007 and 2017 from the Phased Array type L-band Synthetic Aperture Radar (PALSAR), which flies on the Japanese Advanced Land Observing Satellite (ALOS), suggests a decline in overall forest cover. The first above-ground forest biomass map for peninsular Malaysia was developed in 2017 using ALOS PALSAR data. In Andhra Pradesh, India, some smallholder farmers are transitioning from agriculture to plantations. The probability that a farmer or household will adopt forest plantation increases with increased distance to the market and income decreases with the increase in the area of land owned. Using a combination of the Harmonized Landsat–Sentinel-2 (HLS) 10-m (33-ft) surface reflectance data and PlanetScope 3-m (10-ft) data,[12] forests can be separated from other land covers, and plantation forests from natural forests. However, plantation types (e.g., palm vs. banana) are more difficult to discriminate using standard machine learning techniques. For wetland monitoring, integration of Landsat 8, Sentinel-2, and Sentinel-1 data can provide useful information on water-regime mapping.

Forest biomass quantities are poorly documented in different regions of the world—in particular, the tropics. Biomass measurements at higher resolution and with defined error tolerance are needed to address the LUCC-related carbon fluxes. Also, repeated mapping and monitoring of forests is needed to identify deforestation and growth. ESA's Biomass mission[13] will provide such observations. In Malaysia, AGB was derived from airborne lidar at the Ayer Hitam Forest Reserve, which is dominated by dipterocarp forest. The results indicate a high positive correlation between lidar-derived tree height and field-measured tree height. In addition, AGB estimation using airborne and terrestrial lidar in lowland forests showed high correlation.

[12] The PlanetScope constellation is a fleet of 120 satellites, collecting daily 3-5-m (10-16-ft) resolution imagery of Earth's entire landmass.

[13] Biomass is the seventh Earth Explorer mission planned for launch in the 2022 timeframe (*https://go.nasa.gov/33u015L*).

Urban LUCC

In Malaysia, the national government supports the development of *smart cities*, which are defined as cities that are free from physical, social, and mental threats, where the community is able to live in peace and harmony and in a well-protected and conducive living environment. Eight smart-living elements have been identified that include safety and security of people, low-carbon lifestyle, improving housing quality, educational quality, health conditions, cultural facilities, and tourist/recreational attractiveness. In addition, Malaysia's Safe City Programme is being implemented in 150 municipalities to reduce crime. The Programme includes: a street lighting program in different locations; developing a Safe City monitoring web application system wherein people can report crime or unsafe activities directly to police and local authorities online; and crime prevention through environmental design, i.e., designing and managing the built environment to ensure safety in cities. Other presentations in this session stressed the need for more green cover in cities and emphasized that the spatial arrangements and proportions of different land-cover features such as residential, industrial, commercial, and green cover can affect local heating and cooling in urban environments.

Concluding Plenary Discussion

Chris Justice and **Krishna Vadrevu** co-led the final discussion session, which involved all participants, and focused on the SARI regional research needs and priorities. During the discussion, the regional researchers emphasized the need to continue these meetings and training events for the benefit of the larger LUCC community. All agreed that free and open data policies from all regional agencies are needed to strengthen the LUCC research. In addition, attention should be given to transitioning basic research to develop operational satellite-based products. There was also an emphasis on developing guidelines to determine best practices specific to accuracy assessment protocols for LUCC data products. Also, all participants stressed the need for increased capacity building and training activities in the region through SARI activities.

After the discussion session, **Garik Gutman** expressed thanks to all sponsors, participants, and organizers of the meeting, and then adjourned the meeting

After-Meeting Training Sessions

A three-day, hands-on training session was held immediately after the meeting, with participation by 85 young researchers. The focus was on the use of remote sensing and geographic information systems for LUCC applications. The training was organized as a part of the Committee on Earth Observations (CEOS) Working Group on Capacity Building and

Figure. Shown here are photos taken during the three-day SARI LCLUC and CEOS WGCapD training event that followed the SARI LCLUC meeting. These include: the training registration team (UTM) [*top left*]; **Thuy Le Toan** [Centre d'Etudes Spatiales de la Biosphère (CESBIO), France] delivering a training lecture [*top right*]; **Kasturi Kanniah** [UTM, *standing on the right in the bottom left photo*] awarding training a certificate of completion to one of the participants [*bottom left*]; and three different attendees showing their training certificates [*bottom right*]. **Photo credit**: UTM Team

Data Democracy Training [WGCapD], SARI and GOFC-GOLD S/SEA regional network activities. Six international trainers covered a variety of LUCC topics including forest cover mapping and monitoring, forest disturbance mapping, fire detection and monitoring, crop area mapping, and carbon cycle modeling. All training sessions focused on hands-on activities. At the conclusion of the training session, **Kasturi Kanniah** (UTM) awarded certificates of completion to all participants. The photos in the **Figure** [*above*] capture some highlights from the event.

Conclusion

SARI, the NASA LCLUC research initiative, is strengthening land-change science by involving regional scientists. In particular, this meeting highlighted the needs and priorities for SARI and the LCLUC program, which includes an increased emphasis on local LCLUC research and case studies, drivers and impacts of LCLUC, the science of forecasting, interdisciplinary research, and relevance to decision making. The press conference held during the meeting was a great outreach opportunity for meeting participants to connect with the local media and inform them about issues relating to LUCC in Malaysia. The training event, held immediately after the meeting, also went well. It helped to showcase the latest methodologies and NASA LCLUC products. It also engaged several early career researchers in the region to learn about remote sensing and geospatial technologies.

In addition to this summary report, several other meeting outputs either have been or will be produced.[14] The next SARI meeting and training event is planned for late 2020. ■

[14] Three journals plan to publish Special Issues related to topics covered at the SARI LCLUC meeting. They include *Forests*, (*https://go.nasa.gov/2JbvUa1*); *Land Degradation and Development,* (*https://go.nasa.gov/3a1tEhi*); and *Remote Sensing*, (*https://go.nasa.gov/392Ip1Z*).