meeting summaries

Summary of the 2017 LCLUC-SARI International Science Meeting

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Introduction

NASA LCLUC-SARI meeting participants in Chiang Mai, Thailand. **Photo credit:** NARIT team

South/Southeast Asian countries have the highest population growth rate worldwide and account for more than 25% of the global population. This population growth—together with rapid economic development—is leading to the conversion of forested areas to agriculture and agricultural areas to residential and urban uses, with significant impact on ecosystem services. Increased land cover and land-use changes in the region are impacting forest resources, biodiversity, regional climate, biogeochemical cycles, and water resources. To address these issues in the framework of NASA's Land Cover/Land Use Change (LCLUC) Program-funded South/Southeast Asia Research Initiative (SARI), an international science meeting was held in Chiang Mai, Thailand, July 17-19, 2017. The National Astronomical Research Institute of Thailand (NARIT), based in Chiang Mai, hosted the meeting.

The goal of the meeting was to review the availability, potential, and limitations of different satellite data sources and methodologies for land-use mapping, quantification, monitoring, and environmental impact in South/Southeast Asia. Overview presentations described research accomplishments and the current state of scientific information on these topics. The meeting included a poster session with 40 presentations. In total, 165 participants from 16 countries from Asia, Europe, and the U.S. attended the meeting. Scientists from other space agencies also attended, including representatives from the Japan Aerospace Exploration Agency (JAXA), the Space Technology Institute (of Vietnam) and Vietnam National Space Center (VNSC), the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand, the International Centre for Integrated Mountain Development (ICIMOD) in Nepal, as well as representatives from international programs, including the Global Observation of Forest and Land Cover Dynamics (GOFC–GOLD) and Group on Earth Observations' (GEO) Global Agricultural Monitoring [GEOGLAM]. After the meeting, 95 early-career scientists from different countries participated in a three-day, hands-on training, focused on the use of remote sensing and geographic information systems (GIS) for LCLUC applications. The local hosts also organized a two-day field visit that gave meeting participants an opportunity to observe local land cover and land use changes in and around Inthanon National Park in Chiang Mai—see *Field Visit to Inthanon National Park* on page 41.

The meeting had the following objectives:

- to review regional and national science priorities, relating to LCLUC in the region;
- to review the causes and impacts of LCLUC specific to agriculture, forests, urban, and coastal ecosystems;
- to review greenhouse gases (GHGs) and aerosol sources, sinks, and impacts; and
- to strengthen the SARI activities.

Toward those ends, the agenda was organized around the following four themes:

- agricultural LCLUC;
- emission inventories and land-atmosphere interactions;
- urban LCLUC; and
- LCLUC and forestry.

Field Visit to Inthanon National Park Offers Opportunity to Observe Land Cover and Land Use Change in Thailand

The meeting hosts organized an optional two-day field visit to the area in and around Inthanon National Park to give participants an opportunity to see a specific example of how land cover and land-use change issues (e.g., impact of plantations on the land surface) were playing out in a specific case in Thailand. Along the way, participants could see examples of dense and intact cloud forests—see top photo—and other places where the forest has been converted to paddy fields—see bottom photo.

The high mountain cloud forests in Doi Inthanon, Chiang Mai, Northern Thailand, are immersed in fog and rain for much of the year. **Photo credit:** Krishna Vadrevu

Participants also visited the Doi Inthanon Royal Project Foundation (RPF), which is involved in improving the quality of life of local hill tribes through promoting sustainable agriculture, and conservation of forests and water resources. The RPF's activities began in 1969 with the encouragement from His Majesty, King Bhumibol Adulyadej. Since then, RPF activities expanded and currently there are 38 development centers spread across five provinces over the northern part of Thailand including Chiang Mai, Chiang Rai, Mae Hong Son, Lamphun, and Phayao.

These terraced rice fields are located in Pa Pong Pieng Village, northern Thailand, which is located at an elevation of 1022 m (~3353 ft). This is an example of where the forest has been cleared to create agricultural fields; both land cover and land use has changed. **Photo credit:** Krishna Vadrevu

Three panel discussions focused on emerging research questions in agricultural LCLUC, land-atmosphere interactions, and LCLUC in SARI countries. There was also a plenary discussion session that addressed SARI regional science, research, and capacity-building priorities. Meeting presentations are available at *http://lcluc.umd.edu/meetings/lcluc-sari-international-regional-science-meeting-southsoutheast-asia*.

Opening Remarks

The meeting began with welcoming remarks from the local host **Boonrucksar Soonthornthum** [National Astronomical Research Institute of Thailand (NARIT)—*Executive Director*], who stated that NARIT is enabling the development of an international collaborative research network, both regionally and globally, to develop and strengthen knowledge in atmospheric sciences useful for astronomy and to address local air pollution. LCLUC is the main driver of air pollution in Thailand; thus, the current meeting is of immense significance to build collaborations with the international researchers. In this vein, he noted that atmospheric science research at NARIT is being developed by procuring new instruments to address air pollution (discussed later). **Ronald Macatangay** [NARIT—*Atmospheric Science Lead*] welcomed participants and reemphasized that NARIT is strengthening air-pollution measurement capabilities and looking forward to engaging in collaborative research.

Chris Justice [University of Maryland, College Park (UMD), U.S.—*LCLUC Program Scientist*] also gave welcoming remarks, during which he stated that South/Southeast Asian countries are undergoing rapid changes in land cover and land use, and SARI meetings are useful for bringing U.S. and international

scientists together to discuss the latest updates in these areas. **Toshimasa Ohara** [National Institute of Environmental Studies (NIES), Japan] remarked that air pollution in South/Southeast Asian countries is closely tied to land management, so the current meeting provides an important forum to link issues related to land-cover and land-use change in this region with atmospheric science.

Garik Gutman [NASA Headquarters—*LCLUC Program Manager*] provided an overview of NASA's LCLUC Program. He stated that over the last twenty years, the LCLUC Program has supported 267 research projects across many regions of the world—including SARI countries. He stated that the ultimate vision of this program is to develop the capability for periodic global inventories of land-cover and land-use change from space, to develop the scientific understanding and models necessary to simulate the processes taking place, and to evaluate the consequences of observed and predicted changes. Gutman stated that agricultural land use change is important in the SARI region and that agricultural monitoring has emerged as a key priority for the Group on Earth Observations (GEO) program. As crop assessments of both type and condition require nearly weekly data at spatial resolution of less than 50 m (~164 ft), combining data from the joint U.S. Geological Survey (USGS)–NASA Landsat missions and the European Space Agency's Copernicus Sentinel[1] missions can provide data at greater than five-day intervals. He added that in Southeast Asian countries of Myanmar, Cambodia, Vietnam, the Lao People's Democratic Republic (henceforth referred to as *Laos*), and Thailand, rubber and palm-oil plantations have been expanding due to rising prices. In South Asia, especially in Southern India, rice paddy-based farming is being replaced by shrimp farming, and mangrove forests are dwindling in Sundarbans, Bangladesh, and Halong Bay, Vietnam. NASA has funded four different LCLUC synthesis projects in the SARI region. Furthermore, NASA recently funded an interdisciplinary science project focusing on the Lower Mekong River Basin (in the SARI region). More details about the program can be found at *http://lcluc.umd.edu*.

Krishna Vadrevu [NASA's Marshall Space Flight Center—*SARI Lead*] presented the meeting's objectives—summarized in the Introduction. He added that international collaborations are key to building strong SARI–LCLUC research activities. Vadrevu also noted that most SARI meetings and training sessions are funded by several international and regional partners and that SARI is planning to organize additional events with regional partners in the future.

[1] Each Sentinel mission is a constellation of two satellites. In order to fulfill revisit and coverage requirements, they carry a range of technologies, such as radar and multispectral imaging instruments for land, ocean, and atmospheric monitoring. For more information on each mission, see *http://www.esa.int/Our_Activities/Observing_the_Earth/ Copernicus/Overview4*. Subsequent references will be to specific Sentinel missions.

Agricultural LCLUC

Chris Justice presented information on the GEOGLAM initiative, which was first endorsed by the Group of Twenty (G20) Agriculture Ministers in June 2011. GEOGLAM promotes and supports reliable, accurate, timely, and sustained national crop-monitoring information and yield forecasts. He described the development of the UMD agricultural monitoring activities, which started in 2005 with efforts by NASA and the U.S. Department of Agriculture to transition crop analysis from AVHRR[2] to MODIS.[3] At the global scale, GEOGLAM is providing monthly Crop Monitor bulletins (*https://cropmonitor.org*) in partnership with the Agricultural Market Information System, which is hosted at the United Nations' Food and Agriculture Organization (UN FAO), located in Rome, Italy. One of the best examples of GEOGLAM regional coordination is the Asia-Rice project (*http://www.asia-rice.org*) which, as its name implies, focuses on rice-crop estimates and monitoring in Asia. The target products include rice crop area estimates and maps, crop calendars, crop damage assessment, agrometeorological information products, production estimates, and yield forecasting.

Kei Oyoshi [JAXA] presented updates on JAXA's mission and agricultural applications on behalf of the Asia-Rice team, which is comprised of stakeholders involved in rice crop estimation and monitoring for the GEOGLAM initiative. Data from the Japanese Advanced Land Observing Satellite-2 (ALOS-2) are being used to map rice extent in Asia; the International Asian Harvest mOnitoring system for Rice (INAHOR) rice-mapping software has been developed to estimate rice-planted area and specific growth stage using ALOS-2 data. INAHOR has been successfully demonstrated through the Space Applications for Environment (SAFE) and Asia-Pacific Regional Space Agency Forum (APRSAF) projects. With regard to future missions, Oyoshi reported that the Global Change Observation Mission-Climate (GCOM-C) spacecraft is scheduled for launch on December 23, 2017. GCOM consists of two satellite series, the GCOM-Water (GCOM-W) and GCOM-C. GCOM-W, with the Advanced Microwave Sounding Radiometer 2 (AMSR)

[2] AVHRR stands for Advanced Very High Resolution Radiometer (AVHRR), which flies on a series of National Oceanic and Atmospheric Administration (NOAA) Polar-orbiting Operational Environmental Satellites (POES).
[3] MODIS stands for Moderate Resolution Imaging Spectroradiometer (MODIS), which flies on NASA's Terra and Aqua platforms.

onboard, was launched in 2012, and is part of the international A-Train[4] constellation; it measures precipitation, water vapor amounts, wind velocity above the ocean, sea water temperature, water levels on land areas, and snow depths. GCOM-C carries the Second-generation GLobal Imager (SGLI), which will conduct surface and atmospheric measurements related to the carbon cycle and radiation budget, such as horizontal distribution of clouds and aerosols, ocean color, vegetation, and snow and ice. He also mentioned the upcoming Greenhouse Gases Observing Satellite 2 (GOSAT-2), which is a continuation of the GOSAT-1 mission to measure carbon dioxide (CO_2). GOSAT-2 is scheduled for launch in 2018. Oyoshi also reported that Japan is a partner on the upcoming EarthCARE[5] mission, a sun-synchronous satellite that measures the three-dimensional structure of clouds and aerosols; it is also scheduled for launch in 2018. Plans are also underway to launch the Advanced Land Observing Satellite-3 (ALOS-3), an optical mission, and ALOS-4, a radar satellite, in the 2020 and 2020-2021 timeframes, respectively.

Nguyen Lam-Dao [Space Technology Application Center, Vietnam] discussed the rice mapping and monitoring efforts in the Mekong River Delta, Vietnam. Through its participation in the Asia–Pacific Regional Space Agency Forum's (APRSAF) Space Applications for Environment (SAFE) [2013-2017], and GeoRice [2015-2017] projects, data from the Italian Space Agency's COnstellation of small Satellites for the Mediterranean basin Observation (COSMO)-SkyMed, the Canadian Space Ageny's RADARSAT-2, ALOS-2, and Sentinel-1, are being used for rice monitoring. Results suggest that during 2016 rice area was reduced due to water shortages and intrusion of saline water. In addition, two additional projects funded by the state, VNRice and Catch Mekong, are developing rice area maps and crop calendars that include yield estimates. He stated that a national synthetic aperture radar (SAR) satellite, Lotussat-1, is scheduled for launch in 2019, and a Lotussat-2 mission planned for 2022.

Mir Matin [ICIMOD, Nepal] highlighted that ICIMOD is developing operational mapping and monitoring of different crops to support food-security-related decisions in the Himalaya region. In Afghanistan, an annual wheat-area-mapping algorithm is being implemented that integrates phenological characteristics from Sentinel-1 and -2 data using the Google Earth Engine. Also, a Nepali operational agricultural monitoring system is being developed.

[4] "A-Train" is a nickname for the *Afternoon Constellation,* which is the name given to a group of several NASA and international Earth-observing satellites that closely follow one after another along the same orbital "track." To learn more, visit *https://atrain.gsfc.nasa.gov*.

[5] EarthCARE stands for Earth Clouds, Aerosol, and Radiaton Explorer, and is a joint European–Japanese partnership being developed as an Earth Explorers mission under ESA's Living Planet Programme.

Emission Inventories and Land Atmospheric Interactions

Toshimasa Ohara [NIES] presented information on the historical analysis and inverse modeling of air pollutant emissions in Asia. The spatially gridded, Regional Emission inventory in ASia (REAS) has been developed for 1950–2015, covering east, southeast, and south Asian countries at a spatial resolution of 0.25° × 0.25°, monthly, for target species. He stated that emissions of all air pollutants in Asia increased significantly during the six decades of the study, and that sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) seem to have reached their ceiling. There is high uncertainty in the data, especially regarding agricultural emissions and evaporative nonmethane volatile organic carbon (NMVOC) emissions. REAS is now being improved through integrating top-down, inverse modeling, chemical transport modeling, and bottom-up emissions data to reduce these uncertainties.

Eric Vermote [NASA's Goddard Space Flight Center] described the atmospheric correction for Landsat 8 and Sentinel-2 data, and validation of land aerosol and surface reflectance products. He stated that Landsat 8/Operational Land Imager (OLI) and Sentinel-2 surface-reflectance data are largely based on the MODIS Collection 6 algorithm. Vermote also reported that Version 3 of the Landsat 8 surface reflectance product is available, having been validated satisfactorily; and that Version 2 of the Sentinel-2 atmospheric correction algorithm has been successfully implemented.

George Lin [National Central University, Taiwan] explained that the Seven SouthEast Asian Studies (7-SEAS) project[6] is investigating impacts of aerosol particles on weather and the total southeast Asian environment. This campaign has been active since 2007; phase three is currently underway, running from 2016 to 2018. The Spring 2018 campaign will focus on plume-transport to Taiwan from pollution sources on the mainland including Thailand, Vietnam, China, and Hong Kong. The Fall 2018 campaign will collaborate with NASA flight missions scheduled to take place in Southeast Asia.

Ronald Macatangay [NARIT] explained that NARIT-procured aerosol samplers provide fast, reliable, high-resolution aerosol measurements (e.g., total solid particles, particulate matter), from ground level to the troposphere. Plans are underway to establish the Total

[6] 7-SEAS has been established to characterize aerosol-meteorological interactions from Java through the Malay Peninsula and Southeast Asia to Taiwan. Learn more at *https://7-seas.gsfc.nasa.gov*.

Carbon Column Observing Network (TCCON)[7] for measuring CO_2, airborne campaigns to measure pollutants, and to integrate satellite remote sensing data with these measurements to better characterize air pollution in Thailand.

Tsuneo Matsunaga [NIES] showcased the CO_2 and methane (CH_4) emission trends from GOSAT. Results suggest that the East China/Japan region is the largest CO_2 emitter in Asia, and that South and Southeastern Asian regions are almost CO_2 neutral. He then focused on CH_4, showing that East China/Japan and India are important emitters and that models and inventories may underestimate the amplitude of seasonal variations. He mentioned that GOSAT-2, which as mentioned earlier is scheduled for launch in 2018, will have more enhanced Earth-observation capabilities than GOSAT. Matsunga also informed the participants that GOSAT Level-4A CO_2 and CH_4 monthly regional net flux products are now available.

Narisara Thongboonchoo [King Mongkut's Institute of Technology, Thailand] stated that in Northern Thailand, the industrial sector released more NO_x emissions than biomass burning, whereas biomass burning released more carbon monoxide (CO) and particulate matter (PM) than industrial activities. Her presentation emphasized the efforts she and her colleagues are making to integrate satellite and ground-based methods to reduce uncertainties in emission inventories.

Somporn Chantara [Chiang Mai University, Thailand] described the results from open burning combustion chamber experiments. Rice straw, maize residue, leaf litter from mixed deciduous forests, and leaf litter from dipterocarp (mainly lowland rainforest) trees were burnt under controlled conditions. Results suggest that 20-to-25 times more CO_2 was emitted under these conditions than CO. She mentioned that volume aerosol samplers were erected at Mae Hia, Chiang Mai, and Na Noi (all in Nan Province in Thailand) to monitor and analyze ambient $PM_{2.5}$,[8] chemical composition, and toxicity in Northern Thailand.

Paul Griffiths [Cambridge University, U.K.] showcased the results on ozone (O_3) from the United Kingdom Chemistry and Aerosols (UKCA) model. He stated that O_3 is produced mostly in the Northern Hemisphere and lost in the tropics. Land-use change impacts O_3, as loss or gain of vegetation cover can impact O_3 deposition and removal.

[7] To learn more, see "Integrating Carbon from the Ground Up" in the July–August 2014 issue of *The Earth Observer* [**Volume 26, Issue 4**, pp. 13-17—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/JulyAug_2014_color508.pdf*].

[8] $PM_{2.5}$ refers to particulate matter (PM) with a diameter of 2.5 µm or less. (For comparison, 2.5 µm is about 3% of the diameter of a human hair.) These are also known as *fine particles,* as opposed to PM_{10} (with diameter 10 µm or less), which are called *coarse particles.*

Two presentations focused on economic development, urbanization, and emissions. **Prakhar Misra** [University of Tokyo, Japan] stated that air quality in several megacities of India is deteriorating, with industries and construction activities as the major culprits. **Tatsuya Hanaoka** [NIES] summarized the emission reduction strategies specific to CH_4 from the waste sector. He stated that China and Indonesia are the largest emitters of GHGs followed by India, Japan, and Vietnam. Of the different socioeconomic variables, gross domestic product per capita could explain most of the variation in municipal solid waste-related emissions.

Urban LCLUC

The presentations in this session focused on sustainable urban planning in several SARI countries.

Douglas Webster [Arizona State University, U.S.] stated that transportation, thermal power plants, and industries are the three leading sources of GHG emissions in several SARI countries. He mentioned that having green vegetation in urban areas is important for GHG reduction. He then described how an urban plan is driven primarily by housing needs, but should take into consideration vegetation surface characteristics and transportation needs.

Peilei Fan [MSU] showed how urbanization in Vietnam has been driven by economic development (including the inflow of the foreign direct investment), and has worsened local environmental conditions. Meanwhile, in Yangon, Myanmar, productive farmlands are being converted to urban areas.

Mastura Mahmud [Universiti Kebangsaan, Malaysia] highlighted how different cities in Malaysia contribute to local and regional CO_2 emissions. She also described how uncontrolled urbanization in Kuala Lumpur caused green space to decline by 43% between 1990 and 2010.

LCLUC and Forestry

This session included several forestry case studies and showcased tools and techniques useful for forest-based LCLUC studies.

Kenlo Nasahara [University of Tsukuba, Japan] summarized the high-resolution land-cover mapping projects that are ongoing at the JAXA-Earth Observation Research Center (EORC). Multi-temporal ALOS-Advanced Visible and Near Infrared Radiometer type 2 (AVNIR2) high-level products at 10-m (~33-ft) spatial resolution were used to produce a land-cover map for the period 2006-2011, with overall accuracy of 80% (verified from ground-truth observations). ALOS-AVNIR2 data were also used to assess the impacts of

the 2011 nuclear power plant disaster in Fukushima. A global-scale forest/nonforest map from 2007 through 2010, 2015, and 2016 utilizing ALOS Phased Array type L-band Synthetic Aperture Radar (PALSAR)-1 and -2 at 25-m (~82-ft) spatial resolution is also generated. He mentioned that Japan Earth Resources Satellite (JERS)-PALSAR data have been used for high-resolution land-cover mapping in northern Vietnam and agriculture mapping in eastern Thailand. Further, the ALOS-3 optical imaging and ALOS-4 radar missions (previously described) will each add additional land cover and land use change monitoring capabilities.

David Saah [University of San Francisco, U.S.] described the regional land-cover monitoring system (RLCMS) developed as a part of SERVIR's[9] Mekong River Delta-area activities (*https://www.nasa.gov/mission_pages/servir/mekong.html*). RLCMS was developed based on a needs assessment involving government agencies, non-governmental organizations, and research institutions in the Mekong region. He explained that RLCMS has a modular system architecture and runs in the Google Earth Engine to produce useful land-cover maps. For the reference data collection, another tool— "Collect Earth Online"—has been developed (*http://ceo.sig-gis.com/about*). Nearly 20,000 observations on land use and land cover have already been collected using the tool.

Chengquan Huang [UMD] showcased the utility of the Vegetation Change Tracker (VCT) algorithm for forest-disturbance mapping using Landsat data. He stated that the VCT algorithm outputs have been validated across the U.S. and that the North American Forest Disturbance data product that depicts a 25-year history of U.S. forest disturbances is distributed through the Oak Ridge National Laboratory's Distributed Active Archive Center (ORNL DAAC) (*https://daac.ornl.gov/NACP/guides/NAFD-NEX_Forest_Disturbance.html*).

Krishna Vadrevu showcased the potential of Sentinel-1A data for estimating above-ground biomass in different forests in India. He explained that variations in tree density could explain most of the variation in the SAR backscatter signal (they are significantly more correlated than basal area and above ground biomass) and that an exponential model fit well for tree density and above-ground biomass data for both VV and VH[10] backscatter.

Atul Jain [University of Illinois, U.S.] presented details on improving satellite-derived forest-cover dynamics in South and Southeast Asia. He mentioned that differences in satellite-based forest-cover estimates can be attributed to different algorithms, limited ground data used for training and validation, variation in forest cover definitions, and postprocessing methodologies. He emphasized the need to integrate climate and topography information in LCLUC algorithms for better classification accuracy.

Stephen Leisz [Colorado State University, U.S.] explained that the East-West Economic Corridor (EWEC) was envisioned as a project that would upgrade the transportation infrastructure and simplify border controls along a corridor stretching from Da Nang, Vietnam, through Laos, into northeast Thailand, and into Myanmar, ending in Mawlamyine. The goal of the effort is to improve the connectivity within the corridor and to reduce poverty in the area. He then went on to discuss some of the specific urban and rural land cover and land-use challenges specific to drivers in the EWEC countries, which are complicated to address. For example, tree cover seems to be increasing in some locations and decreasing in others. Urban encroachment on rural areas is happening across three countries, with Thailand being most advanced and Laos the least.

Birendra Bajracharya [ICIMOD] stated that LCLUC activities in ICIMOD are driven by application needs in Nepal. Sample projects undertaken by ICIMOD include quantifying LCLUC dynamics in Kangchenjunga, estimating soil-erosion dynamics in the Koshi River Basin, assessing flood damage in Bangladesh, and SERVIR-funded decadal LCLUC analysis in Hindu Kush Himalayas. A *mountain geoportal* for dissemination of data and applications has been developed. ICIMOD recently signed a memorandum of understanding with Global Forest Watch, and is collaborating with USGS SilvaCarbon (*https://egsc.usgs.gov/silvacarbon/node/30.html*) and UMD team on LCLUC studies.

Rabin Raj Niraula [HELVETAS Swiss Intercooperation, Nepal] showed that in Nepal, deforestation due to agricultural expansion is most common; however, afforestation programs and community-based forest-management activities also assisted forest regrowth in several regions. He mentioned that the rate of annual deforestation decreased from 1.7% per

[9] SERVIR is not an acronym; it's a Spanish word that means "to serve." It is a joint venture between NASA and the U.S. Agency for International Development (USAID) that provides state-of-the-art, satellite-based Earth monitoring, imaging and mapping data, geospatial information, predictive models, and science applications to help improve environmental decision-making among developing nations. The lower Mekong River Basin in Southeast Asia is one of their "hubs," along with the Hindu–Kush region of the Himalayas; they also have two other "hubs" in Africa.

[10] VV and VH stand for vertical transmit and vertical receive and vertical transmit and horizontal receive, respectively. These are polarization channels for a radar system. To learn more about polarization in radar systems, visit *http://www.nrcan.gc.ca/node/9567*.

year during the 1990s to 0.18% per year in 2014, and implied that sustainable forestry management involving local people is the best way to mitigate deforestation.

Faizul Bari [Forest Department, Pakistan] stated that in Pakistan, 5.5% of the country is occupied by forests, which are rapidly degrading due to heavy demand for timber and fuel wood, overgrazing, conversion to agriculture, construction of Eucalyptus and populus plantations, housing development, and infrastructure development. He stressed the need for regular mapping and monitoring of LCLUC, proper land-use planning and governance, and increased awareness for sustainable development.

Soe Myint [Arizona State University, U.S] stated that over the span of 14 years (2000-2014), a total of 215,680 ha of mangrove forest was lost in Myanmar, with an annual mean deforestation rate of 2.21%.Also, a projected net change rate of 1% of mangrove loss per year will result in a mean annual change in Net Primary Productivity rate of three metric tons of carbon per year per square kilometer. He used these results to emphasize that conserving mangrove vegetation is of high importance in Myanmar.

Mani Murali [National Institute of Oceanography] stated that in the region near the delta of the Mahanadi River in India, sandy areas, fallow lands, and mudflats are decreasing as the area around the river is converted to croplands and built-up areas. Human intervention in the hinterlands is affecting the coastal systems, and decreased sediment flux, cyclones, and floods are the main causes of erosion in the region.

Three presentations focused on LCLUC specific to plantations. **Louis Lebel** [Chiang Mai University, Thailand] mentioned that socioeconomic development as reflected in Gini[11] household income trajectories has been uneven in Thailand. Boom and bust development (e.g., the buildup of rubber and palm-oil production in recent years, leading to an abundance of these items, and a consequent decline in prices) has impacted landscapes and livelihoods. Scenario studies suggest that continued expansion of rubber and fruit trees at the expense of forests will impact watershed services.

Jefferson Fox [East–West Center, U.S.] stated that national policies and variables relating to global markets (i.e., supply, demand, and price) have been driving rubber production expansion in Southeast Asia. Due to such expansion, indigenous households have been losing access to land and are forced to relocate to marginal lands. Labor is becoming scarce and will eventually become more problematic than access to land. Fox emphasized the need for more integrated studies to address LCLUC, their drivers, and socioeconomic impacts.

Randolph Wynne [Virginia Polytechnic Institute, U.S.] stated that plantation forestry is rapidly expanding in Asia and that understanding the drivers and ramifications of the presence of these new trees outside forest landscapes is vital. Specific to Andhra Pradesh in southern India, the drivers of plantation expansion include availability of marginal lands, absentee landlords, low maintenance, and productive pest-resistant species.

Discussion Sessions

Across the three sessions, panel members and participants were asked to identify important research priorities. In addition, a plenary discussion session was organized on SARI regional science, research, and capacity-building priorities. The **Table** [below] summarizes the discussions from each of the three panels and captures the most pressing issues and research priorities.

[11] The *Gini coefficient* or *Gini ratio* (when it is normalized) is the most widely used single-summary number for judging the wealth distribution of a particular nation; in essence, it gives a measure of economic equality.

Table. Summary of Topics Raised During Discussion Sessions

Topic Area	Specific Topics Discussed
Agricultural LCLUC	• Addressing urban agricultural land encroachment • Combating pollution related to biomass burning of agricultural residues • Developing operational tools for mapping of crops • Developing seasonal weather forecasts to allow farmers to better manage crop calendars • Creating operational tools to monitor agricultural productivity and diseases including early forecasting • Forging international cooperation on free and open sharing of data useful for agricultural applications • Capacity building and training activities on the use of new technologies

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Table. Summary of Topics Raised During Discussion Sessions. (cont.)

Topic Area	Specific Topics Discussed
Land-Atmosphere Interactions	• Addressing transboundary air pollution problems • Mitigating pollution through development of sustainable technologies • Mitigating biomass burning pollution • Understanding regional and global linkages in land-atmospheric interactions • Developing high-resolution emission inventories integrating top-down and bottom-up inventories • Conducting missions and source apportionment studies • Understanding aerosol-cloud-radiation interactions • Improving accessibility to tools for atmospheric research studies • Capacity building and training relating to atmospheric modeling • Open data sharing mechanisms
LCLUC	• Connecting land cover with land use • Assessing land-use and land-cover changes related to water quality degradation and alleviated cross-border water conflicts • Improving understanding of impact of land-cover and land-use change impacts on the larger system—e.g., some afforestation in Nepal leads to reduced irrigation for agriculture • Reducing GHG emissions from land-cover change especially in peatlands and restoring traditional forests • Deciding how to best communicate results and research findings to share with stakeholders and interested communities, generally

Conclusion

The meeting's presentations and discussion sessions focused on synergies among various approaches and provided recommendations on how to improve the role of Earth observations, ground data, and modeling techniques to improve our understanding of LCLUC in SARI countries. Participants identified the need to develop regionally consistent LCLUC products, and all participants agreed on the need to develop mission-effective strategies to transition from research to operational products to help inform policy. Common issues that surfaced during the discussions included the need to strengthen research, capacity building, and training activities in South/Southeast Asian countries. Overall, the meeting was highly successful in addressing LCLUC issues in South/Southeast Asia.

Request for papers: As a part of the meeting outputs, papers are being solicited on LCLUC in South/Southeast Asia, to be part of a Special Issue of the International Journal of Digital Earth. All researchers working on LCLUC in South/Southeast Asia are invited to submit articles at *http://explore.tandfonline.com/cfp/est/ijde/si-4*. Plese email **Krishna Vadrevu** (*krishna.p.vadrevu@nasa.gov*) for additional details. ■