COMMENTARY:

Combining satellite data for better tropical forest monitoring

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Implementation of policies to reduce forest loss challenges the Earth observation community to improve forest monitoring. An important avenue for progress is the use of new satellite missions and the combining of optical and synthetic aperture radar sensor data.

Monitoring of changes in tropical forest cover has relied predominantly on optical satellite sensors because of their relative ease of processing and interpretation and the continuity of medium-resolution (10–30 m) observations since the 1970s[1,2]. Spaceborne synthetic aperture radar (SAR) data have the advantage of providing cloud-free observations, but these data have been comparatively underutilized in operational programmes[1,2]. It is rarer still for optical and SAR data to be used in combination, despite increasing evidence of the benefits of this approach.

Recent developments and limitations

Optical remote sensing has seen major scientific breakthroughs over the past decade, leading to operationalized forest cover change methods applied at regional[3,4] to global scales[5,6]. The majority of tropical countries are using Landsat imagery as the primary source of information to support their forest change assessments[1,7]; however, a common limitation is persistent cloud cover. Although this can be partly overcome by the compositing of images, cloud persistence in some regions, such as the northwest and northeast Amazon and Central Africa (for example, Gabon and the Democratic Republic of Congo), means that data gaps remain, even when compositing is performed over a period of up to three years[4,8]. The low availability of usable optical images during the rainy season therefore presents a challenge for interannual analysis and timely detection of newly changed areas.

A recognized advantage of SAR is that microwaves penetrate clouds and smoke haze, and by using longer wavelength L-band SAR, forest and non-forest areas can be well differentiated. Time-series data from the Advanced Land Observing Satellite (ALOS) Phased Arrayed L-band SAR (PALSAR) have been used for gap-free annual mapping of forest and non-forest areas at regional and global scales[9]. Shorter wavelength C- and X-band SAR have also been used for forest change mapping, although rapid saturation of the signal can limit discrimination, for example, between regenerating forests and crop lands. When compared with developments in optical-based approaches, there have been fewer advances towards operationalized SAR monitoring.

The combination of SAR and optical image time series for the detection of tropical forest cover change, and the associated technical challenges, have been addressed by several studies in recent years[10–12]. A clear reduction of cloud-induced data gaps, improved accuracy in the detection of forest and non-forest areas, and reduced detection lags were achieved[11,12]. Even for areas with persistent cloud, sub-annual forest change monitoring was possible. However, the time series fusion approaches used in these studies were only demonstrated at a local scale and were not demonstrated for large-area monitoring.

Why the reliance on optical data only?

Data from Landsat and other optical sensors have been available since the 1970s (Fig. 1), initially over regions with ground stations and then globally since the implementation of the Landsat 7 Long-Term Acquisition Plan in 1999. The opening of the Landsat archive in 2008 effectively catalysed developments in optical-based forest monitoring. The sudden availability of medium-resolution time-series imagery for the past four decades, free of charge and with user-friendly data access, the provision of open source pre-processing algorithms, the ability to download fully pre-processed (surface reflectance) images, and an increase in affordable computer processing and storage capability led to three major transitions in the field: (i) from bi-temporal to time-series-based change detection methods, (ii) from coarse-resolution to medium-resolution applications, and (iii) from local- to global-scale products. This resulted in a broad acceptance of 'ready to use' Landsat imagery as the major data source for large-area forest cover change detection[1,13].

Fragmented and inconsistent data archives are a problem common to many SAR missions, as data have traditionally been collected for local or regional studies. Consequently, opportunities to integrate optical and SAR systems have been limited by differing data availability and acquisition dates. As a result, data from different satellite missions have rarely been used in combination to track forest changes in the tropics. The Japanese Earth Resources Satellite 1 (JERS-1) SAR (1992–1998), ALOS PALSAR (2006–2011) and ALOS-2 PALSAR-2 (since 2014) are the exceptions, as they are the first SAR missions with semi-continental or global systematic acquisition strategies.

The commercial data policy of ALOS PALSAR and many other past and current SAR missions has delayed full scientific exploitation of the data produced and impeded operational developments. In the case of L-band SAR, which has had a well-established research community involved in forest applications since the mid-1990s, the recent commercialization of

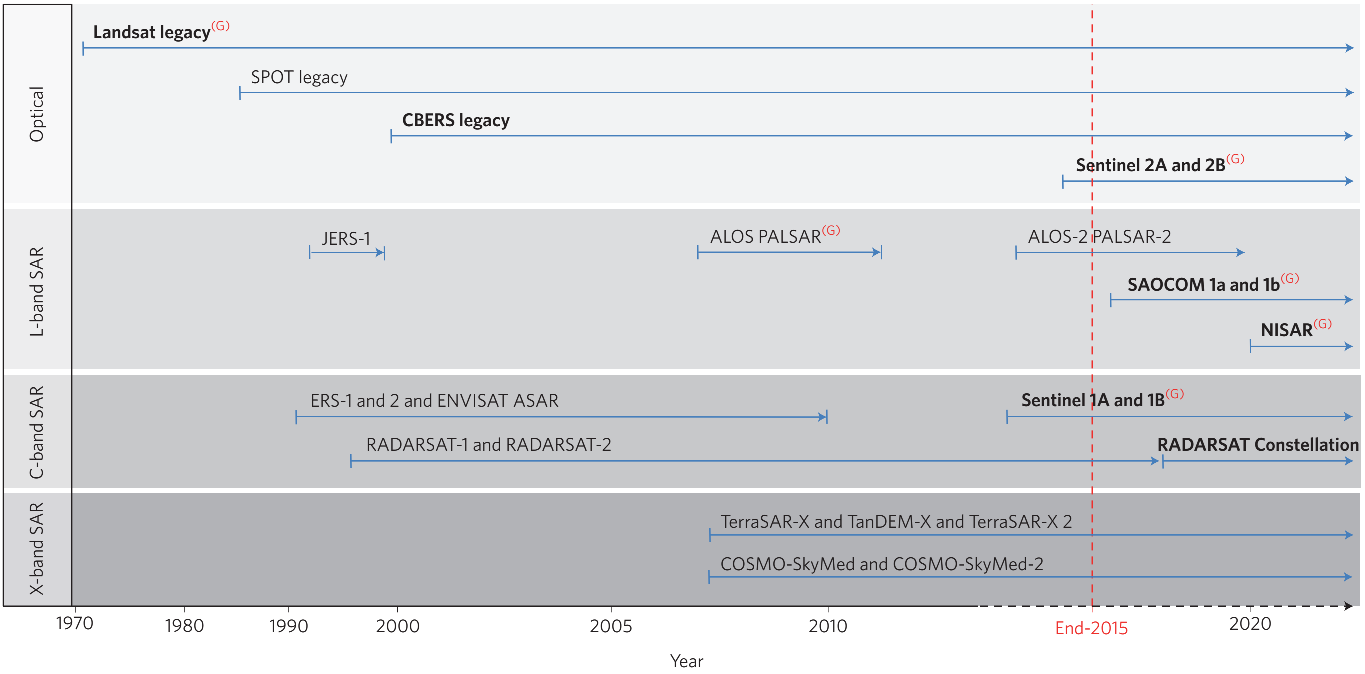

Figure 1 | Current and anticipated medium-resolution optical and synthetic aperture radar (SAR) missions to support worldwide forest monitoring. Missions with a free-of-charge data access policy are in bold and missions with a restricted data access policy in mid-2015 are in a normal font. Missions with a continuous global acquisition strategy are denoted with a red (G); other missions feature a local- or regional-only acquisition strategy.

key L-band missions has resulted in a loss of momentum in the operationalization and upscaling of existing applications and a missed opportunity to reach out to potential new user groups. As developing tropical countries avoid relying on costly remote-sensing data for their measurement, reporting and verification processes under the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) programme[7,14], only a very few make use of SAR data[1]. Furthermore, as many users are less able to process, interpret and analyse SAR compared with optical data, the willingness to assess its usefulness is even less if there is a cost associated with it.

The large majority of Earth observation research groups have also traditionally specialized in either optical or SAR remote sensing, and therefore multi-sensor SAR-optical developments have not been a focal area. This research compartmentalization prohibits the discovery and exploitation of the full potential of SAR-optical approaches, and resolution of associated technical challenges.

Traditional data-handling strategies, which rely on the processing of locally downloaded and stored satellite imagery, are ill-suited to large-area multi-sensor time-series applications. Hansen *et al.*[5] demonstrated how to process large parts of the Landsat archive for the twenty-first century using the storage and processing capabilities of the Google Earth engine. However, simultaneously dealing with several data streams from both optical and SAR sensors in different formats, gaining access to global datasets and running spatial applications present new challenges.

A pledge for action

Developments towards operationalized approaches that combine optical and SAR image time series are paramount if we are to use the impending stream of medium-resolution and globally available optical (Landsat 8, Sentinel-2) and SAR (ALOS-2 PALSAR-2, Sentinel-1) data in a way that improves the consistency and robustness of tropical forest cover monitoring. Guaranteeing a minimum number of observations over the dry and wet seasons provides greater opportunity for sub-annual monitoring and rapid change detection; for example, for a better understanding of the causes, dynamics and impacts of changes as some drivers (for example, fires[15]) are clearly season dependent. In particular, Sentinel-1 has significant potential as, for the first time, dense SAR time-series data are provided over tropical forest areas free and openly. Such potential surely needs to be utilized.

To make this possible, relevant satellite data need to be freely available, as this will stimulate algorithm development and their wide-area use. Building confidence in multi-sensor approaches and demonstrating the associated gains in accuracy of forest cover change estimates is also fundamental to achieving national policy-level acceptance of multi-sensor imaging as a reliable source of information for tropical forest monitoring. Sentinel-1 already provides C-band time series free of charge, and freely accessible L-band data is in sight with the upcoming SAOCOM-1 (Satélite Argentino de Observación Con Microondas; 2016) and NISAR (Nasa-Isro Synthetic Aperture Radar; 2020) missions. However, the public release of the JERS-1 SAR, ALOS PALSAR and ALOS-2 PALSAR-2 data would also be extremely helpful; to achieve this, a discussion of potentially viable business models needs to be started.

Space agencies and other satellite data providers need to better accommodate the increasing demand for consistent long time series instead of single-date images. Access to, and distribution of, time-series imagery covering the entire timespan of satellite archives should be as user-friendly and straightforward as possible. Implementing a Landsat-like Earth observation data infrastructure for SAR missions that, for example, allows the generation of time series by simply stacking a set of downloaded pre-processed images, would greatly improve exploitation of these data. In addition, more free and open-source pre-processing and analysis tools would boost the usage and exploitation of the data beyond a relatively small group of experts. This would stimulate capacity building in developing countries so that they can focus on continuous improvement, with better use of SAR data to complement their optical monitoring systems.

More integrated optical and SAR groups and closer cooperation between research teams is needed to exploit the full potential of SAR-optical remote sensing and to address the arising technical challenges. Recognizing the importance of the Landsat science team for the success of Landsat, and the Kyoto and Carbon Initiative for the progress of L-band SAR applications, a joint science team of optical and SAR experts would clearly be beneficial to extending optical and SAR-based processing and analysis.

Big-data-related issues also need to be addressed. The large and increasing quantity of optical and SAR data requires a shift from downloading of data for local storage and processing, to centralized storage and remote processing of the data on large servers and high-performance facilities. Data infrastructures are required to host and process large volumes of time-series data from several sensors. For example, it may be possible to capitalize on Australian and NASA data cubes or the European Space Agency's thematic exploitation platforms.

Funding opportunities for multi-sensor research beyond mission and country-specific programmes are needed to stimulate priority technical research. Space agencies and other research and development organizations are encouraged to issue more dedicated open calls for proposals that address operationalization of multi-sensor approaches and international partnerships.

The alignment of optical and SAR data for forest monitoring requires a willingness by the two communities to work together and advance algorithms for forest cover change detection that go beyond what can be achieved using either dataset alone. The development and implementation of such algorithms in an open-source environment and based on centralized high-performance computing can be realized with investment and by champions in relevant fields. Realizing these monitoring opportunities would underpin policies to reduce forest loss and provide an improved chance of achieving long-term conservation and sustainable use of forests.

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COMMENTARY:

Intact ecosystems provide best defence against climate change

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Humans are adapting to climate change, but often in ways that further compound our effects on nature, and in turn the impact of climate change on us.

Climate change is affecting people and nature across every continent and ocean[1]. Changes in rainfall, snow and ice melt are impacting water resources in terms of quality and quantity. Drought, crop failure and poor yield, and human heat-related stress and mortality are increasing in frequency. Sea-level rise is displacing coastal and island communities through storm surges and saltwater incursion, and deglaciation and range shifts of species on land and sea are leading to loss of ecosystems and creation of new and different ecological communities.