TOFDRY - Trees outside forests in global drylands

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The number of trees growing outside of forests and their role in the global carbon cycle are one of the major unknowns in terrestrial research. This is because the spatial resolution of traditional satellite images is too coarse to detect trees growing in isolation without forming a forest. Our study recently published in Nature (doi: 10.1038/s41586-020-2824-5) was the first using thousands of satellite images at sub-metre resolution coupled with artificial intelligence to detect and measure billions of individual trees in the Sahara and Sahel, both dryland areas formerly known as desert or grassland. The study raised major attention, and this project will extend on this by creating unprecedented knowledge on non-forest trees in global drylands.

Mitigating climate change while securing livelihoods is a major societal challenge in the 21st century. In this context, trees and shrubs (hereafter collectively referred to as trees) play a key role, as trees constitute a stable carbon sink while providing ecosystem services to the local population.

Quantifying and monitoring the world's trees is thus of highest importance; however, current assessments and statistics focus on trees within forests, overlooking trees outside forests. These non-forest trees are mainly located in drylands, which are hyper-arid, arid, semi-arid and dry sub-humid lands, covering ~65 million km² of the Earth's land surface. Typical landscapes that include non-forest trees include savannas, settlements, farmlands, but also deserts and other lands with sparse vegetation.

However, most scientific and non-scientific attention is devoted to forests, largely ignoring trees that do not form a closed canopy, in spite of several studies suggesting that trees outside forests exceed the resources provided by forests for numerous countries. The extent of non-forest trees has thus never been systematically assessed at large scale, so it has never been possible to study their impact on biochemical cycles as well as their economic or ecological importance at large scales.

The trees outside the forests

Trees have always been a central element in environmental sciences and policies: threats of deforestation, looming desertification, 'stop encroaching deserts' and 'plant a tree' campaigns have been on front pages for decades.

The trees outside forests support the livelihoods of a vast number of people through subsistence use of products, such as wood (construction, fuel), food, fodder, and medicinal plants; cash income obtained from the sale of products; and ecological benefits such as protection against hazards (e.g. erosion) and improving agricultural productivity. Moreover, trees in sparse vegetation areas (e.g. the Sahara) are an essential factor for the survival and biodiversity of flora and fauna. Finally, trees outside forests constitute an important carbon pool and impact the climate by lowering the albedo, affecting the aerodynamic roughness, and through transpiration.

While forests are monitored on a routine basis, attempts to quantify the density of trees outside forests have been limited to relatively small sample sizes and/or local field surveys. This is because of the scattered nature of dryland trees, which limits assessments based on commonly available satellite technologies (10 to 30m resolution) to uncertain estimations of the canopy coverage per area, thereby leaving a blind spot with respect to the number, location and size of individual trees. Moreover, most studies do not cover areas of sparse vegetation, thereby completely overlooking trees in semi-arid, arid and hyper-arid regions.

The limited attention devoted to the quantification of individual trees outside forests does not only cause a great underestimation of their ecological and economic functions, but it also leads to misinterpretations in the extent of tree cover, and confusion related to its definition and the characteristics of woody plants included in calculations of 'coverage'. For example, existing maps of tree cover or carbon stocks are, at their best, based on 30x30m data, which cannot capture scattered isolated trees in sparsely vegetated areas, resulting in misleading interpretations and the general consensus that dryland areas like the Sahel or Sahara are largely free of trees. Furthermore, trees in global farmlands (agroforestry) are a largely overlooked carbon stock, also contributing to soil fertility and livelihoods.

Mapping and monitoring individual trees

This project builds on two revolutionary developments impacting on the field of remote sensing which potentially allow the mapping and monitoring of individual trees outside forests in great details at a continental scale, introducing variables that go beyond woody cover and opening new perspectives for research in the context of ecosystem services.

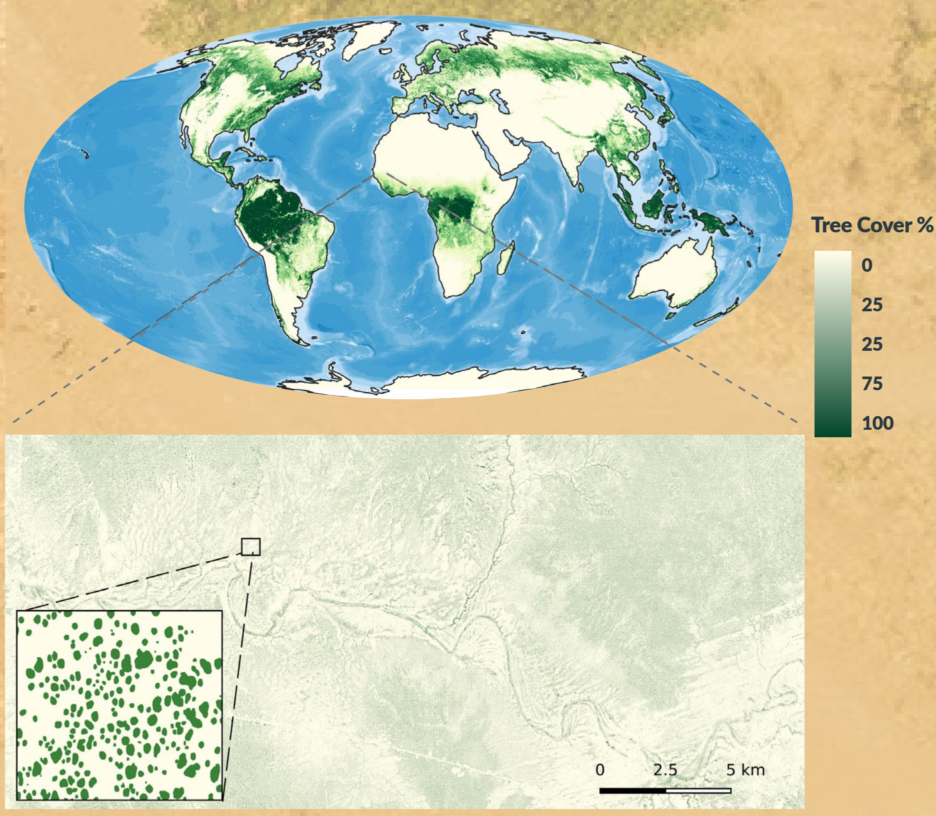

Figure 1: Seeing the forests and the trees: forests in a previously published global tree-cover map are defined as more than 25% canopy closure of trees taller than 5m (Hansen et al., 2013). This definition does not apply in most dryland areas, as in these regions trees grow mostly as isolated plants. Our recently published study in Nature mapped all trees (>3-m2 crown size) in an area covering 1.3 million km² using deep learning applied to submetre-resolution satellite imagery. The rectangle shows an example area including a detailed zoom-in (Brandt et al., 2020).

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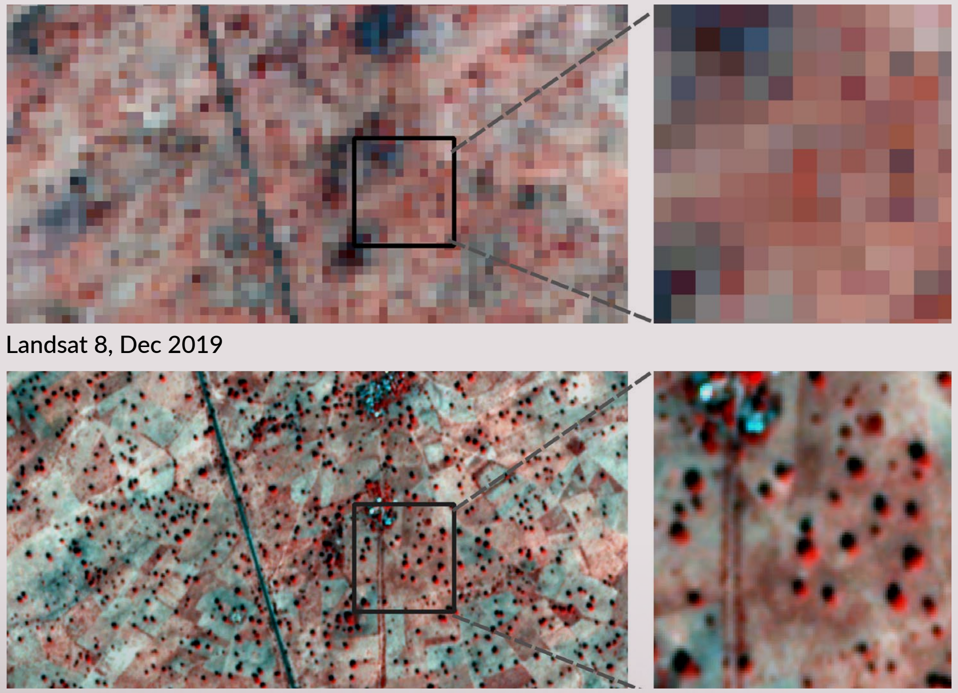
First is the massive increase in available data with petabytes of images recorded by satellites every year. With the low priced PlanetScope constellation from Planet Labs, global data recorded at a high-frequency approach a spatial resolution that allows the visual identification of single objects such as trees.

Second is deep learning which has been the main driver of tremendous progress in artificial intelligence over the last decade. Deep learning has proven to be a disruptive technology in many areas (e.g., speech and natural language processing, medical image analysis, etc.). With the availability of a new generation of satellite imagery at an unprecedented spatial resolution, a massive impact of artificial intelligence (AI) on remote sensing appears inevitable.

However, surprisingly little work has been conducted combining high spatial resolution satellite images and deep learning at large scales, and even if we may witness a surge in AI-related research in various fields in the coming years, a key missing point will often be the missing application and validation. This project is motivated by the following shortcomings of existing research:

- Global tree cover maps undervalue dryland areas.
- Existing studies on dryland woody vegetation are limited to 'canopy coverage' and are highly uncertain.
- Manual sampling approaches are subjective and contested.
- There is no applicable framework to map isolated non-forest trees in satellite images.



Landsat 8, Dec 2019

PlanetScope, Dec 2019

Figure 2: Trees that grow in isolation and do not form larger canopies are invisible in normal satellite imagery (here the widely used Landsat is shown). Consequently, they are not part of any national, regional or global assessment on tree cover. The lower part of the figure shows that individual trees can be clearly identified in PlanetScope imagery that will be the backbone of this project. This example shows a farmland area in Senegal, West Africa, a dryland region where rainfall is not sufficient for closed canopy forests.

- The distribution, canopy cover, and density of non-forest trees is unknown at large scales.
- The economic and ecological values of non-forest trees is unknown at country scale.
- The role of drylands in the global carbon cycle is highly uncertain.
- There is no baseline on the extent of non-forest trees which is needed for research, dynamic vegetation models, policies and decision-making.

This project will closely collaborate with NASA and the DFF Sapere Aude project "Trees outside forests in African drylands" and conduct the first wall-to-wall identification of non-forest trees in global drylands using very high spatial resolution satellite imagery and deep learning to study the extent and the role of dryland trees as a carbon sink and their contribution to livelihoods.

Project objectives

The overall aim of this project is to address the aforementioned shortcomings. Specifically, this project will address three main objectives:

- Develop and apply cutting-edge deep learning techniques to detect non-forest trees and their properties in very high spatial resolution satellite imagery for global drylands.
- Assess ecological services provided by non-forest trees as well as socio-environmental variables determining the distribution and properties of non-forest trees.
- Gain new insights into temporal dynamics of dryland trees related to human management, policies and climate extremes.

Revolutionary satellite data: the PlanetScope constellation owned by PlanetLabs consists of hundreds of micro-satellites that capture the entire Earth at 3m resolution every day. For the first time, affordable satellite data are available at a spatial resolution high enough to capture single trees.

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PROJECT NAME

Trees outside forests in global drylands

PROJECT SUMMARY

This project aims towards a wall-to-wall identification of trees in global drylands, and study their ecological services and socio-environmental determinants. The project will apply a new generation of satellite imagery at sub-meter resolution and extensive field data in conjunction with fully convolutional neural networks, a deep learning technique being able to identify objects within imagery at an unprecedented accuracy. In doing so, we will lay the groundwork for new insights into the contribution of human agency and climate change to the distribution of dryland trees and their role in mitigating degradation, climate change and poverty.

PROJECT LEAD PROFILE

Martin Brandt received his PhD in 2014 and has been working at the University of Copenhagen since 2015. His research interest is remote sensing of the environment with a special focus on African drylands and southern China.

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