remote sensing

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Editorial

Remote Sensing of Savannas and Woodlands: Editorial

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1. Background

Savannas and woodlands represent one of the most challenging targets for remote sensing. They provide a complex gradient of woody and herbaceous plant species that varies widely in spatial arrangement, plant density and height, and canopy persistence (evergreen to deciduous) of the woody plant component. The understory component also varies from annual to perennial grassland, and pure grassland to a complex mix of grasses, forbs, palms, cycads and small shrubs. Savannas and woodlands are geographically associated with grasslands, shrublands and dry forests at their dry margins, and temperate and tropical forests at the wet margins. Savannas are generally regarded as an intermediate state between grassland and forest maintained by herbivory and wildfire and influenced by climatic and edaphic characteristics.

The grasslands, savannas and woodlands of sub-Saharan Africa played a key role in development of the remote sensing of vegetation cover and dynamics [1–7]. This vegetation provided a fertile target for the earliest applications of the Normalized Difference Vegetation Index (NDVI) and introduced the public to large-scale regional dynamics of climate-driven vegetation growth. Although there is wide geographical variation in the density and seasonality of woody canopies, savannas and woodlands are associated with highly seasonal climates, and the pattern of vegetation greening and browning detected by space-borne sensors is largely driven by the behavior of the understory. Despite this, much of the attention on remote sensing of savannas and woodlands has historically focused on the woody component.

Since the 1980s, savannas and woodlands have continued to be at the forefront of developments in remote sensing. Savannas and woodlands were the target for international projects aimed at understanding ecosystem behavior such as the Hydrological Atmospheric Pilot Experiment (HAPEX) Sahel [8], the Southern Africa Regional Science Initiative (SAFARI 2000) [9] and continued studies along the Northern Australian Tropical Transect [10], all of which have included major remote sensing components especially utilizing the Advanced Very High Resolution Radiometer (AVHRR) and the MODerate resolution Imaging Spectroradiometer (MODIS). African savannas have played an important role in assessing the potential of radar backscatter for retrieval of, for example, herbaceous biomass with the European Remote sensing Satellite (ERS) wind scatterometer [11] and woody biomass with the Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar (ALOS PALSAR) [12]. Since wildfire is such an important feature of savannas, these ecosystems have been, and continue to be, at the forefront of the development of fire products such as hotspots and burned areas [13]. In the absence of a satellite-based imaging spectrometer with a high signal-to-noise ratio, especially in the short-wave infrared range, airborne spectrometers alone and in association with full-waveform lidar have been used to characterize the biochemistry [14], floristics [15], structure [16,17] and species composition [18] of savannas at the landscape scale.

Savannas and woodlands, especially in Africa and South America, deserve increased attention for remote sensing studies since they are prime candidates for agricultural conversion, important resources for livestock production and subsistence of indigenous communities, and could play a significant role in signaling vegetation shifts driven by the

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interaction of climate change and rising atmospheric CO_2 concentrations. This Special Issue sought to provide an overview of the application of the latest sensors and sensor combinations to retrieval of quantitative properties of savannas and woodlands. It was hoped that contributions would illustrate improvements in retrievals of attributes of cover components and component dynamics and relate these attributes to the wide diversity of issues faced by savanna and woodland systems globally.

2. The Papers

The papers provide a very current perspective on remote sensing of savannas and woodlands and reflect both methodological trends, and geographical imperatives driven by threats. An analysis of word frequency in the abstracts from the 12 papers, using Wordclouds.com, revealed several specific points of focus (Figure 1). The word cloud is presented with six types of words. The most common "ecosystem" words were *tree*, *soil* and *water*. *Grassland*, *forest* and *species* were present but less common in keeping with a continued emphasis on the woody component of savannas and woodlands. Among "climate-related" words, *season* and *dry* were most common matching the broad climatic characteristics of savannas and woodlands involving distinct periods of growth, senescence and dormancy. Among the "process" words, *spatial*, *trends*, *phenology*, *distribution*, *change* and *time* were most common reflecting interest in the arrangement of vegetation, the interaction of climate and growth pattern and the driving forces affecting savannas and woodlands. The "method" words were dominated by terrestrial laser scanning (*TLS*) and related acronyms (*ULS*—unmanned aerial vehicle laser scanning; *MLS*—mobile laser scanning), and by *NDVI* and *indices*, indicating the legacy of those initial remote sensing studies discussed above and the enduring value of the NDVI. More generic words such as *sensor*, *images*, *mapping*, *analysis*, *area*, *difference*, *scale* and *monitoring* were also common. The papers also used an array of space-borne sensor systems including Landsat, MODIS (various products), Sentinel 1, Sentinel 2, ALOS PALSAR and Compact High Resolution Imaging Spectrometer (CHRIS). Several studies used combinations of sensor types including optical, SAR and LiDAR. The "geography" words were dominated by *cerrado* and *Brazil* with *biome* and *global* next most common. However, the 11 research papers provide a relatively balanced coverage of savanna and woodland geography, with four articles on South America, two articles on Africa, two articles on Australia, one each on North America and Europe, and one article with global coverage. Finally, the "attribute' words included *types*, *structure*, *AGB*, *biomass*, *woody*, and *density* reflecting the fundamental characteristics of savannas and woodlands that need to be measured and that make them a complex target for remote sensing.

The Special Issue is nicely balanced in terms of geography and technology. It has two feature topics: the Cerrado and bordering ecosystems; and laser scanning as the technology of the moment for characterizing savanna vegetation structure. The Special Issue is conceptually organized in the first instance by geography. The lead article [19] covers the global extent of grasslands and savannas using the MODIS sensor and provides global geographical context. This is followed by the feature review on TLS in savannas [20]. The articles then follow global geography starting in the southern hemisphere dealing with TLS in the Australian tropical savanna [21,22]. Next come four articles on various aspects of savanna and woodland vegetation in Brazil [23–26]. These are followed by two articles on African environments that include a mix of savannas and woodlands and other vegetation [27,28]. The final two articles address functional ecological aspects of two different types of northern hemisphere oak savannas in North America [29] and Europe [30].

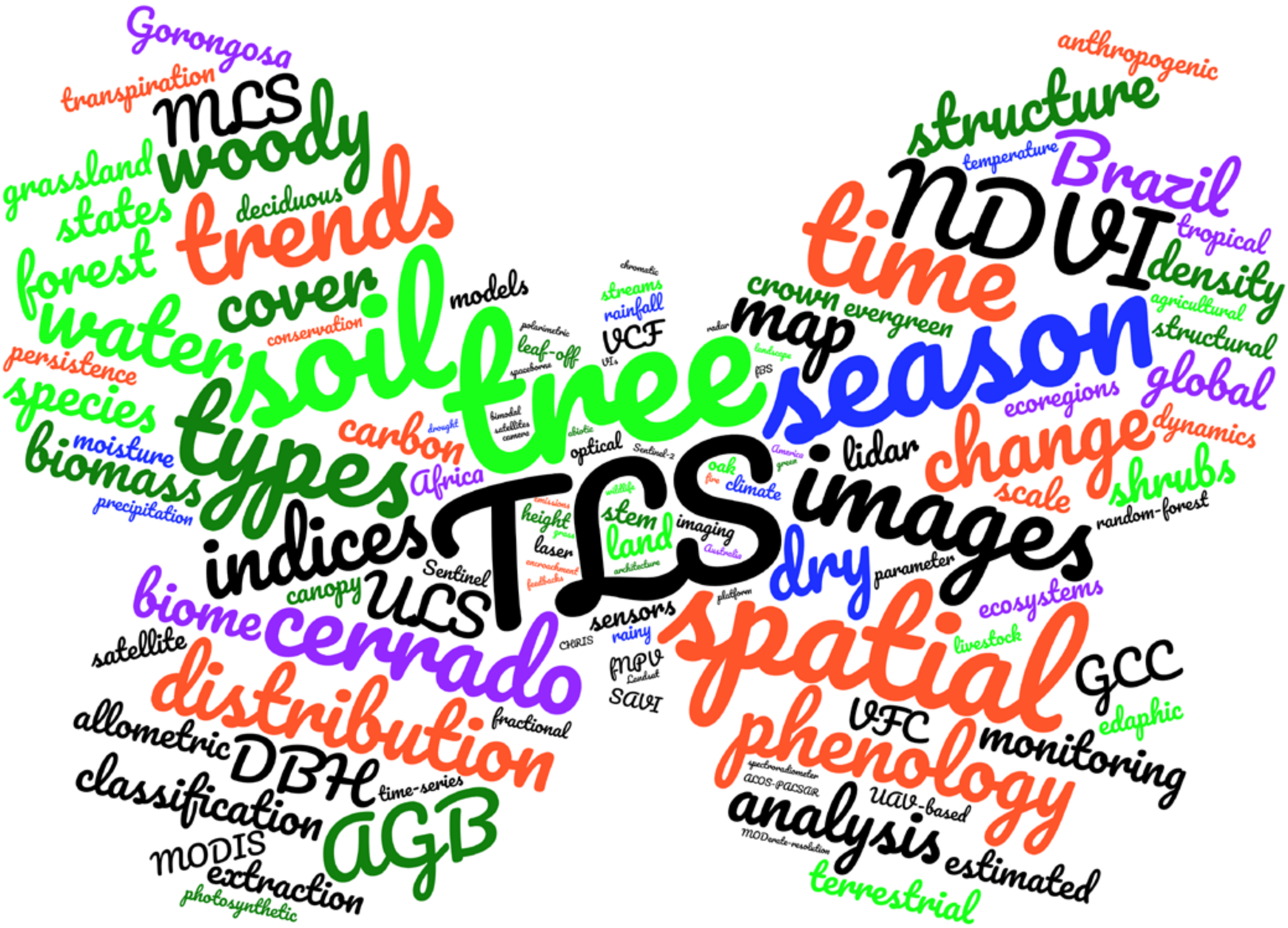

Figure 1. Word cloud based on the article abstracts (two occurrences or more). The terms *savanna*, *woodland*, *remote* and *sensing* are excluded since they are the topic of the Special Issue. Words represent all versions of the term or concept, e.g., season includes seasonal and seasonality. Only place names and acronyms are capitalized. Color scheme: light green—ecosystem words; blue—climate -related words; red—process words; black—method words; purple—geography words; and dark green—vegetation attribute words. Word cloud produced on http://wordclouds.com (accessed on 6 April 2021).

The group of four papers on South America span the ecotone from the heavily altered Mato Grosso forests in Amazonia through the savanna of the Cerrado to the dry forests of the Caatinga. These papers explore the mapping of vegetation types [23], the measurement of woody above-ground biomass (AGB) [24], the long-term change in savanna vegetation [25] and water use [26]. The emphasis on this continuum from tropical rainforest through savanna to dry forest is timely and important as this environment is subject to massive anthropogenic change and complex political forces within Brazil that influence the balance between conservation and exploitation of these ecosystems. The paper by de Souza Mendes [23] uses multiple satellite sources of SAR imagery with Sentinel 2 data to distinguish among forest and woody savanna types in the Cerrado. The paper by Bispo et al. [24] combines airborne LiDAR with Landsat 8 and ALOS PALSAR to map AGB for a catchment-scale study region of the Cerrado. The paper by Paloschi et al. [26] reports on the strong dependence of water use on soil moisture, and the variation in phenology, and physiology of individual species in this dry, fragile Caatinga environment. The paper by Alencar et al. [25] is a new and significant documenting of long-term change in natural native vegetation in the Cerrado using 33 years of Landsat imagery in the Google Earth Engine. This is already the most viewed and cited article in this Special Issue.

The review of the application of TLS with a focus on savannas [20] and the two papers focused on the application of TLS in savannas and woodlands of Northern Australia [21,22] form the second feature topic. The review [20] and the article by Levick et al. [22] are complementary in that the former identifies both the value of TLS in savannas, and the limited application and potential issues, whilst the latter explicitly answers issues surrounding the spatial extent and structural complexity by demonstrating the value of combining TLS, ULS and MLS. Both articles are important contributions to the literature and to the application of laser scanning in savannas and woodlands. The paper by Luck et al. [21] provides an example of retrieval of savanna structure using TLS and an explicit description of a northern Australian savanna in the wet tropical zone.

The article by Hill and Guerschman [19] describes the MODIS Global Vegetation Cover Product and characterizes trends in vegetation cover fractions between 2001 and 2018 across global savannas and woodlands as well as associated grasslands. The study documents trends in non-photosynthetic (dry or brown) vegetation for the first time and identifies grasslands and savannas with concerning positive trends in the bare soil fraction. The two articles based in Africa explore aspects of savanna and woodland vegetation structure and temporal persistence using MODIS data. Kumar et al. [27] examine apparent differences in spatial structure of woody vegetation across sub-Saharan Africa retrieved from different MODIS products. They suggest that multimodal spatial structure is regionally disaggregated, and that apparent spatial structure retrieved may be dependent upon the remote sensing product and spatial scale of retrievals. Herrero et al. [28] provide a temporal study of the Gorongosa National Park in Mozambique which explores the persistence of the MODIS NDVI signal in relation to changes in precipitation in the period since the year 2000. The study reveals a decline in vegetation as measured by NDVI persistence especially in grassland and rainforests potentially associated with declining precipitation.

Oak savannas were once much more common in temperate ecosystems forming an ecotone between grassland and forests. The two articles published here represent two major types: the perennial grass/oak savannas that stretched from southern Canada to northern Mexico between the grasslands and forests of North America; and the annual grass/oak savannas found, for example, in California and Spain. The paper by Hill et al. [29] describes the use of a rare time series from the CHRIS hyperspectral sensor to explore functional phenology of the woody canopy in a conserved but degraded post oak savanna in Texas invaded with evergreen shrubs. The results of this study hint at the value of hyperspectral data in characterization of differences in canopy properties and species mixtures that are important in the evolution of disturbed remnant landscapes. However, they also emphasis the limitations of 20-year-old low signal-to-noise imaging spectrometer data, and the gaping chasm in the capability of satellite remote sensing for quantitative retrievals of vegetation canopy biochemistry waiting to be occupied by a state-of-the-art imaging spectrometer. By contrast, Gómez-Giráldez et al. [30], examine the phenology of the tree and understory layers in relation to soil water dynamics in an annual grass/oak savanna in Spain using a Sentinel 2 time series. The study showed a high degree of synchrony between NDVI and soil moisture. However, some vegetation indices were potentially sensitive to subtle variations in chlorophyll content of the understory grassland.

The featured emphasis on TLS [20–22] and the Cerrado [23–26] points to the technology currently at the cutting edge for remote measurement, and to the focus of concern for the fate of carbon stocks and biodiversity in one of the largest savannas in the world. The adoption of Sentinel 2 [23,30], the application of big-data processing [25] and the combination of SAR, LiDAR and optical data [23,24] signal the future direction of remote sensing of savannas from space. Multi-sensor imaging and multi-scale laser scanning are necessary to truly capture the three-dimensional properties of savannas and woodlands. It notable that only two papers were focused on the understory grassland [19,30]. Nevertheless, there is still a role for polar orbiting medium resolution sensors [19,27,28] and a pressing need for a for a modern imaging spectrometer in orbit.

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