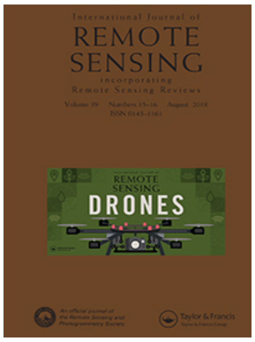

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PREFACE

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Unmanned Aerial Systems (UAS) for environmental applications special issue preface

Anita Simic Milas[a], Joaquim João Sousa[b], Timothy A. Warner [c], Ana Cláudia Teodoro[d], Emanuel Peres [b], José Alberto Gonçalves[d], Jorge Delgado Garcia[e], Ricardo Bento[f], Stuart Phinn[g] and Amy Woodget[h]

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This special issue on Unmanned Aerial Systems (UAS) for Environmental Applications makes three important contributions:

(1) It marks the launch of a new section in the *International Journal of Remote Sensing* (*IJRS*), which we have called *Drones*.
(2) It captures key contributions from the 5th Small Unmanned Aerial Systems (sUAS) for Environmental Research (UAS4Enviro2017) conference, which was held at the University of Trás-os-Montes e Alto Douro, Portugal, from 28 to 30 of June 2017.
(3) It collects a wide range of papers on UAS, in addition to those presented at the conference.

Drones are indeed a key new technology for remote sensing, and one that has grown rapidly in recent years. According to the database, Web of Science (published by Clarivate Analytics), the first significant use in *IJRS* of any of the terms UAS, unmanned aerial vehicle (UAV) or drones, for example, in the title, abstract, or keyword of an article, was in 2009, in a paper by Dunford et al. (2009). It was not until 2012 that another paper used one of those terms. After that, the numbers increased very quickly, and by 2017, *IJRS* published 68 papers that referenced these terms. Most notably, 2017 also saw the first *IJRS* special issue on UAS, titled 'Unmanned aerial vehicles for environmental applications' (The Editors 2017). This current special issue is a direct follow-on from that major collection of papers, and the fact that we are able to have two major special issues on this topic in the space of just over one year, is further evidence of its importance.

By placing UAS papers in the new *Drones* section of *IJRS*, we aim to foster dialogue amongst the UAS community, and highlight the rapid advances made in this field. However, the need for a separate section for drone-related work may not seem

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immediately apparent. In many ways, remotely sensed data acquired from UAS platforms have properties not unlike those of traditional aerial and satellite-borne remote sensing. Certainly, UAS platforms can potentially fly instruments that are similar to, albeit generally much smaller than, those flown on satellites, including a variety of imaging devices, such as multispectral (Franklin and Ahmed 2018), hyperspectral (Miyoshi et al. 2018), thermal (Brenner et al. 2018; Witczuk et al. 2018), radar, and lidar sensors.

Nevertheless, in other ways, UAS data differs in important ways from that acquired from satellite, and even traditional aerial platforms, and thus a separate *IJRS Drones* section can help to focus research attention on UAS-specific questions (Lippitt and Zhang 2018). The most striking feature of UAS data is the very fine spatial resolution that is possible, as small as centimeter scale (or potentially even finer scales), as is demonstrated by many of the papers in this special issue. For example, Pádua et al. (2018) produce images with 2.4–3.8 cm pixels, and Zhou et al. (2018) images with 5 cm pixels. Though scientists are only just beginning to explore remote sensing at this scale, this fine resolution allows a fundamentally different scale of feature to mapped, such as small weeds in an agricultural field (Stroppiana et al. 2018).

The ability to acquire one's own data means that imagery from drones can be collected at a time specified by the user, and not on some arbitrary day and hour, determined by satellite orbital geometry. This not only allows greater flexibility in experimental design, but raises fundamental questions about optimal timing of image acquisition for the question being studied (Witczuk et al. 2018), as well as providing opportunities to ask entirely new questions, such as those requiring repeat imaging over a short period of time (e.g. over a single day). In addition, commonly used techniques to produce orthophotos, such as structure from motion, generate point cloud data that imply an inherent three dimensional structure to the data (Guerra-Hernández et al. 2018), unlike in conventional single-frame satellite imagery. This allows not only the production of high spatial resolution digital elevation models (DEMs) (e.g. a 5 cm DEM by Gonçalves, Pérez, and Duarte 2018), but allows the third dimension to be an integral part of image analysis techniques, such as the individual tree identification work of Carr and Slyder (2018).

A common feature of much drone research is the use of camera data. In this special issue, almost all the papers use cameras of some sort – either single cameras or banks of cameras, such as the Mini-MCA6 (built by Tetracam Inc.) multispectral six-camera array (Franklin and Ahmed 2018). In many cases, though, remote-sensing scientists are turning to consumer grade cameras, with broad sensitivity to red, green, and blue (RGB) wavelengths. These cameras are used either as they are provided by the manufacturer, or customized to convert one of the RGB bands (such as the red band) to a near-infrared band, by removing the filter over the relevant detectors that would otherwise constrain the camera to visible wavelengths (Lu, He, and Liu 2018).

The importance of cameras in drone imagining has prompted a resurgence of interest in applied photogrammetry. Furthermore, unlike in a satellite image, which is acquired very rapidly, and from a relatively stable and simple geometry, drone-based orthoimagery may incorporate hundreds to even thousands of images, with complex geometry, acquired over an extended period of time. Converting such data to physical units of radiance or reflectance format is no small challenge. Yet, many years of satellite imaging research has provided strong evidence that staple remote-sensing techniques such as image ratios, of which the normalized difference vegetation index is but one example, require images in reflectance format. For repeat imaging, such as time-series analysis, conversion of the arbitrary digital numbers to physical units, is also generally important. This special issue addresses many of these topics. For example, four papers focus on radiometric calibration and conversion to reflectance (Coburn et al. 2018; Logie and Coburn 2018; Mafanya et al. 2018; Miyoshi et al. 2018). Two papers focus on mosaicking and the generation of seam lines between images (Song et al. 2018; Tian, Sun, and Wang 2018). Georeferencing, a key challenge in images with very fine resolution, is a focus of the paper by Gabrlik et al. (2018).

Processing of UAS data poses its own challenges (Lippitt and Zhang 2018). Ruiz et al. (2018) evaluate an Iterative *K*-nearest neighbour (KNN) classification approach for high spatial resolution data, and Serifoglu Yilmaz et al. (2018) survey commercial and non-commercial point cloud filtering programmes. Singh and Frazier (2018) provide a meta-analysis of UAS acquisition and processing used in 412 papers. Their findings indicate the need for an increased focus on standardization, data quality evaluation, and uncertainty characterization.

The most commonly used UAS platform in this special issue is the multirotor (also known as a multicopter). We have chosen this iconic device as the logo for our new *IJRS Drones* section. However, we should not forget that alternative platforms, such as fixed wing UAS (e.g. Su et al. 2018), offer their own strengths. Kite photography, though much more rare, offers particular advantages in areas with strong winds (Wigmore and Mark 2018).

The importance of drones for remote sensing is demonstrated by the tremendous breadth of applications in this special issue. The most common applications are in vegetation mapping, including the following:

- Invasive species (Baron, Hill, and Elmiligi 2018; Mafanya et al. 2018)
- Individual tree delineation (Carr and Slyder 2018; Guerra-Hernández et al. 2018)
- Forest regeneration (Goodbody et al. 2018; Röder et al. 2018)
- Tree species classification (Franklin and Ahmed 2018)
- Evapotranspiration (Brenner et al. 2018)
- Vegetation biophysical and biochemical properties (Lu, He, and Liu 2018)
- Environmental bio-remediation monitoring (Capolupo et al. 2018)
- Leaf litter mapping (Zhou et al. 2018)

UAS applications in agriculture are clearly also very important. Hunt and Daughtry (2018) provide an overview of the potential, and perhaps more crucially, current limitations of UAS for agricultural purposes. Other agricultural applications addressed in this issue include the following:

- Crop phenotyping (Di Gennaro et al. 2018)
- Vineyard properties (Pádua et al. 2018)
- Sugarcane yield (Sanches et al. 2018)
- Chlorophyll content (Simic Milas et al. 2018)
- Mapping weeds in rice (Stroppiana et al. 2018)
- Mapping smallholder crops (Yonah et al. 2018)

Papers addressing geomorphologic applications include the following:

- Foredune topographical mapping (Gonçalves, Pérez, and Duarte 2018)
- Beach morphodynamic changes (Talavera et al. 2018)
- Landslide mapping (Seier et al. 2018)

Other applications include river water quality mapping (Larson et al. 2018) and earthquake disaster mapping (Xu, Wu, and Zhang 2018). Two papers address animal remote sensing, a topic for which high spatial resolution drone data would appear particularly suitable; Witczuk et al. (2018) survey ungulates, and Su et al. (2018) survey wild yaks.

This special issue also demonstrates the international interest in UAS technology. The issue as whole incorporates 36 papers from 14 countries in Africa, Asia, Europe, North America, and South America:

- Austria (2 papers)
- Brazil (3 papers)
- Canada (6 papers)
- China (5 papers)
- Czech Republic (1 paper)
- Germany (1 paper)
- Italy (3 papers)
- Poland (1 paper)
- Portugal (3 papers)
- South Africa (1 paper)
- Spain (1 paper)
- Tanzania (1 paper)
- Turkey (1 paper)
- USA (7 papers)

With this evidence of wide support for UAS research, we look forward to a vibrant future for the new *Drones* section of IJRS, and the continued growth of this research area.

Disclosure statement

No potential conflict of interest was reported by the authors.

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