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Dynamic ecological observations from satellites inform aerobiology of allergenic grass pollen

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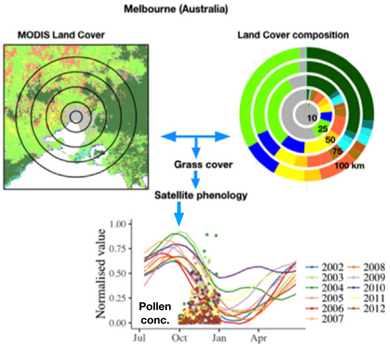
HIGHLIGHTS

- Grass pollen was studied across five sites in Australia and France.
- Study utilised satellite-derived greenness data to inform grass pollen aerobiology.
- Cross-site timing differences were found in greenness phenology and pollen release.
- Generalised additive models predictive of grass pollen across the diverse sites.
- Potential of satellite data to augment short-term pollen forecast models.

GRAPHICAL ABSTRACT



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ABSTRACT

Allergic diseases, including respiratory conditions of allergic rhinitis (hay fever) and asthma, affect up to 500 million people worldwide. Grass pollen are one major source of aeroallergens globally. Pollen forecast methods are generally site-based and rely on empirical meteorological relationships and/or the use of labour-intensive pollen collection traps that are restricted to sparse sampling locations. The spatial and temporal dynamics of the grass pollen sources themselves, however, have received less attention. Here we utilised a consistent set of MODIS

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satellite measures of grass cover and seasonal greenness (EVI) over five contrasting urban environments, located in Northern (France) and Southern Hemispheres (Australia), to evaluate their utility for predicting airborne grass pollen concentrations. Strongly seasonal and pronounced pollinating periods, synchronous with satellite measures of grass cover greenness, were found at the higher latitude temperate sites in France (46–50° N. Lat.), with peak pollen activity lagging peak greenness, on average by 2–3 weeks. In contrast, the Australian sites (34–38° S. Lat.) displayed pollinating periods that were less synchronous with satellite greenness measures as peak pollen concentrations lagged peak greenness by as much as 4 to 7 weeks. The Australian sites exhibited much higher spatial and inter-annual variations compared to the French sites and at the Sydney site, broader and multiple peaks in both pollen concentrations and greenness data coincided with flowering of more diverse grasses including subtropical species. Utilising generalised additive models (GAMs) we found the satellite greenness data of grass cover areas explained 80–90% of airborne grass pollen concentrations across the three French sites ($p < 0.001$) and accounted for 34 to 76% of grass pollen variations over the two sites in Australia ($p < 0.05$). Our results demonstrate the potential of satellite sensing to augment forecast models of grass pollen aerobiology as a tool to reduce the health and socioeconomic burden of pollen-sensitive allergic diseases.

1. Introduction

Grass pollen are the most widespread allergens globally with elevated levels of airborne grass pollen linked to increases in hospital emergency department visits and admissions for asthma (Darrow et al., 2012; Erbas et al., 2015). Climate variability, warming temperatures and increased CO_2 levels have been associated with altered flowering times (Fitter and Fitter, 2002), extended pollination periods and increased allergen loads within pollen, thereby increasing human exposure to aeroallergens (Beggs, 2016). The frequency of high pollen concentration days and thunderstorm asthma events are projected to intensify with climate change, further escalating the substantial public health burden of allergic respiratory diseases (Beggs, 2016; Dabrera et al., 2013; Davies et al., 2015).

Management of pollen allergen exposure is an increasingly important public health concern for reducing the health and socio-economic burden of allergic diseases (Beggs et al., 2015; Guillam et al., 2010). Long-term airborne pollen records have been integral towards measuring population exposures in Europe, USA, and other countries, and also provide valuable indicators of current and future trends in allergenic pollen production (Ziello et al., 2012; Ziska et al., 2011). However, conventional methods for sampling airborne pollen utilise volumetric spore collection traps that are labour-intensive, expensive to maintain, and confined to a restrictive range of sampling sites.

Short-term seasonal pollen forecast models have been employed to assist in management of symptoms and disease. These forecast models aim to predict the start of a local pollen season and days of high airborne pollen concentrations utilising meteorological variables (e.g., temperature, relative humidity, wind and precipitation), and may include empirical relationships with airborne pollen concentrations (Laaidi, 2001; Ong et al., 1995; Smith and Emberlin, 2006), as well as local expert knowledge and patients' symptom reports. However, forecast models based on pollen concentration data from one site are not likely to be suitable in other environments (Green et al., 2004). Other observation-based forecasting approaches utilise time series modelling of inter-annual variations in pollen concentrations (Aznarte et al., 2007), meteorological data-driven machine learning and computational intelligence (Voukantsis et al., 2010), and process-based models of chilling requirements (Linkosalo et al., 2008) and photoperiod (García-Mozo et al., 2009).

An important shortcoming in pollen forecasting methods is their lack of utilisation of available ecological information on current land cover conditions, plant species composition (McInnes et al., 2017), and the timing of key plant phenophase periods, such as budburst and flowering. Such data are vital to understand the ecological and climate drivers of pollen aerobiology and may aid the prediction of short-term and future trends of pollen aerobiology. For example, modifications in land cover and land use activities, such as livestock grazing practices, can alter grassland extent, species composition, and flowering phenology, thereby impacting pollen aerobiology in complex ways (Grimm et al., 2008; Rogers et al., 2006; Skjøth et al., 2013).

In the past decade there has been an increase in the availability of satellite remote sensing data of ecologically relevant landscape variables that can augment the restrictive coverage afforded by in situ pollen networks. Satellite data provide timely and repetitive updates of land cover conditions and vegetation phenology status at high spatial resolution (Justice et al., 1998; Zhang et al., 2006). Spatial and temporal analysis using satellite greenness or vegetation indices (VI), have been shown to provide accurate estimates of the onset of birch flowering in Norway (Karlsen et al., 2009), grass and birch flowering in the UK (Khwarahm et al., 2017), the location of grass pollen sources in urban areas in Denmark (Skjøth et al., 2013) and juniper pollen sources in the US (Luvall et al., 2011).

In this study, we investigated the utility of globally consistent satellite remote sensing measures of grass cover and extent and their dynamic phenological growing periods, to inform temporal changes of airborne grass pollen in five contrasting urban environments in the Northern (France) and Southern Hemispheres (Australia). Our aim was to assess the potential of satellite data to augment pollen forecast models and help answer complex questions of changing grass pollen exposure and management of current and future public health threats.

2. Methods

2.1. Site description

Three ‘temperate, warm summer, without a dry season’ climate sites (Köppen-Geiger Climate Class – Cfb, Peel et al., 2007) in France and two in Australia, with analogous periods of pollen data, were studied (Fig. 1). The sites in France were at higher latitudes (46–50°N) relative to the Australian sites (34–38°S). The two Australian sites and one site in France (Amiens) were coastal and at low elevation (<75 m above sea level), while the other two sites in France were inland with elevations above 175 m.

The two Australian sites had bi-modal seasonal rainfall patterns in contrast to a single summer rainfall season in the three French sites (Fig. 2). Mean annual rainfall (MAR) varied from 634 to 1348 mm and mean annual temperatures (MAT) varied from 10.4 to 17.6 °C. Sydney and Lyon sites had similar and high rainfall (~1300 mm/year), while Melbourne, Montluçon and Amiens had similar and low rainfall (~700 mm/year). All sites had spring seasonal periods of increasing temperatures and vapour pressure deficits (VPD). Wind speeds were high across Austral spring and summer periods in the Australia sites and were high across winter and spring periods in the sites in France (Fig. 2).