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Mapping the birch and grass pollen seasons in the UK using satellite sensor time-series

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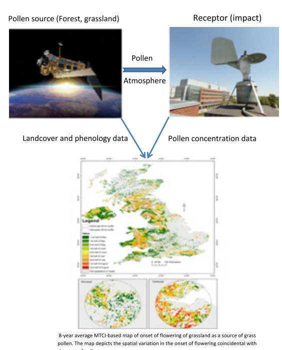
HIGHLIGHTS

- A novel method was developed to estimate onset of pollen season from RS data.
- Strong positive correlation between the onset of pollen season and pollen data
- Onset of pollen season for birch and grass is mapped at a high spatial resolution.

GRAPHICAL ABSTRACT



8-year average MTCI-based map of onset of flowering of grassland as a source of grass pollen. The map depicts the spatial variation in the onset of flowering coincidental with the start of pollen season.

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ABSTRACT

Grass and birch pollen are two major causes of seasonal allergic rhinitis (hay fever) in the UK and parts of Europe affecting around 15–20% of the population. Current prediction of these allergens in the UK is based on (i) measurements of pollen concentrations at a limited number of monitoring stations across the country and (ii) general information about the phenological status of the vegetation. Thus, the current prediction methodology provides information at a coarse spatial resolution only. Most station-based approaches take into account only local observations of flowering, while only a small number of approaches take into account remote observations of land surface phenology. The systematic gathering of detailed information about vegetation status nationwide would therefore be of great potential utility. In particular, there exists an opportunity to use remote sensing to estimate phenological variables that are related to the flowering phenophase and, thus, pollen release. In turn, these estimates can be used to predict pollen release at a fine spatial resolution. In this study, time-series of MERIS Terrestrial Chlorophyll Index (MTCI) data were used to predict two key phenological variables: the start of season and peak of season. A technique was then developed to estimate the flowering phenophase of birch and grass

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Hay fever
Predicting model
MERIS MTCI
Onset of birch flowering
Onset of grass flowering
Onset of greenness

from the MTCI time-series. For birch, the timing of flowering was defined as the time after the start of the growing season when the MTCI value reached 25% of the maximum. Similarly, for grass this was defined as the time when the MTCI value reached 75% of the maximum. The predicted pollen release dates were validated with data from nine pollen monitoring stations in the UK. For both birch and grass, we obtained large positive correlations between the MTCI-derived start of pollen season and the start of the pollen season defined using station data, with a slightly larger correlation observed for birch than for grass. The technique was applied to produce detailed maps for the flowering of birch and grass across the UK for each of the years from 2003 to 2010. The results demonstrate that the remote sensing-based maps of onset flowering of birch and grass for the UK together with the pollen forecast from the Meteorology Office and National Pollen and Aerobiology Research Unit (NPARU) can potentially provide more accurate information to pollen allergy sufferers in the UK.

1. Introduction

Early prediction of allergenic pollen concentration in the air can be valuable for medical professionals, allergy sufferers and pharmaceutical companies. The increasing prevalence of allergenic diseases, mainly hay fever, triggered by aeroallergens affects hundreds of millions of people worldwide (Bousquet et al., 2008). In the United Kingdom, the most common types of allergenic pollen are birch and grass which, respectively, affect approximately 25% and 95% of the population of hay fever sufferers (Emberlin et al., 1999). The most common species of birch in the UK are Downy birch (*Betula pubescens*) and Silver birch (*Betula pendula*). The former is the most abundant birch in Scotland and North West England. In contrast, Silver birch is most common species in the South and South East England. In the UK, there are about 150 species of grass of which around 12 species contribute significant amounts of pollen to the atmosphere. This high number of species makes prediction of grass pollen difficult (Emberlin, 2009). In the UK and parts of Europe the overall prevalence of hay fever is approximately 15–20% (Emberlin et al., 1997; Aas et al., 1997; Varney et al., 1991). The highest prevalence occurs in late adolescence/early adulthood, with between 8 and 35% of young adults in the European Union having IgE (Immunoglobulin E) serum antibodies to grass pollen (Burr, 1999; D'Amato, 2000). High prevalence rates were recorded for many parts of the world, both for grass and birch pollen (Bousquet et al., 2007). The prevalence of sensitivity to grass and birch allergens varies geographically depending on the source abundance and the amount of allergen extract on the pollen (Buters et al., 2012). The length of the grass and birch pollen seasons also varies both spatially and temporally. This is due to variation in the factors that influence the abundance and dispersal of pollen such as local vegetation type, altitude, land use and climate (Galán et al., 1995; Emberlin et al., 1997; Emberlin et al., 1999; Emberlin et al., 2000). Europewide, grass pollen is the most widely spread aeroallergen with the highest concentrations in the Western Iberian Peninsula, central Europe and the UK (Skjøth et al., 2013a).

Birch and grass aeroallergen concentrations in the UK are usually predicted based on current and past meteorological data together with pollen concentration data collected at a specific pollen station, landuse, topography, local phenological observations and empirical research (Adams-Groom et al., 2002; Emberlin et al., 2007; Skjøth et al., 2015a; Skjøth et al., 2015b). The predictions in some parts of Europe are also partially established using empirical models (Laaidi, 2001; Chuine and Belmonte, 2004; García-Mozo et al., 2009; Smith et al., 2009), sometimes in conjunction with pollen dispersion simulation models such as COSMO-Art, for example, which is currently used in Switzerland (Zink et al., 2012, 2016). Empirical models are well-known for their limitations as they are specific to the area where they are produced (Stach et al., 2008), such as large urban areas like London (Smith and Emberlin, 2005a) and Copenhagen (Skjøth et al., 2008a), that are known to have a warmer climate compared to their surroundings. Moreover, the spatial representation of these prediction models is low as pollen grains are generally collected from a limited number of pollen monitoring sites. Within the urban environment, gardens and small woodlands are considered to be an important source of birch pollen in the atmosphere of cities (Skjøth et al., 2008b) and urban environments often have advanced flowering during spring compared to the surrounding rural landscape due to the urban heat island effect (Estrella et al., 2006; Neil and Wu, 2006). Similarly, grass areas are commonly found in or near urban areas (Pauleit and Duhme, 2000) and it has been shown that these urban sources can cause considerable variation in the grass pollen load throughout the urban landscape (Skjøth et al., 2013b). Any characterisation of flowering and overall pollen concentration obtained using a fixed and small number of pollen sampling stations will therefore be limited. Additional information about grass phenology and in turn the timing of their pollen release at finer spatial resolution would therefore be highly useful. For the UK, this is particularly relevant due to its unique composition; a patchy landscape that includes some of the largest urban areas in Europe (Skjøth et al., 2013b). Over the last three decades development of new satellite sensors and availability of these data at a high temporal frequency provided the opportunity to estimate vegetation phenological variables at regional to global scale (Lloyd, 1990; Reed et al., 1994; Fisher and Mustard, 2007; Roerink et al., 2011; Jeganathan et al., 2014).

Phenological variables derived from temporal profiles of satellite-derived vegetation indices can be used to characterize the stages of vegetation development during the growing season (Olsson et al., 2005; Heumann et al., 2007; Seaquist et al., 2009; Reed et al., 2009; Beurs de and Henebry, 2010; Roerink et al., 2011). Thus, they can be related to biological definitions of plant phenology, for example, the flowering phenophase related to pollen release. Satellite sensor imagery has the advantage that it provides spatially complete coverage that can be used to interpolate traditional ground-based phenological observations. Linkosalo (1999, 2000) found in southern Finland that the difference in time from birch (*Betula pendula*) male flowering to the first date of budburst was only 1.1 days, with male flowering occurring first. Thus, the timings of male flowering and leaf budburst of birch are well correlated ($r = 0.97$). Moreover, the timing of male flowering, leaf budburst and pollen release appear to be quite closely synchronised (Newnham et al., 2013). This indicates that birch phenophases, observed as leaf budburst or, for example, greenness of birch trees, could be used to determine the timing of local birch pollen release. This suggests that measurements of the flowering phenophase of grass and birch from remote sensing could be used to map local pollen release nationwide (Karlsen et al., 2009).

Satellite sensor images have been used widely to detect variables related to vegetation phenology, for example, the start of season and end of season (Lloyd, 1990; Reed et al., 1994; Fisher and Mustard, 2007; Dash et al., 2010; Roerink et al., 2011), but to a lesser extent for the flowering phenophases which for some species are during or before budburst (e.g. for birch) and for others are at a different growth stage (e.g. for grass). One reason may be related to the fact that phenological phases at the species level are most easily observed with remote sensing in areas where the observational target (e.g. birch) is the dominant species. This is the case for birch in Scandinavia (Skjøth et al., 2008b), while oak and beech outnumber birch in most other European countries