Interactive comment on "Development and evaluation of pollen source methodologies for the Victorian Grass Pollen Emissions Module VGPEM1.0" by Kathryn M. Emmerson et al.

Anonymous Referee #2

General comments: I would like to thank Ms Emmerson and colleagues for submitting an interesting and detailed manuscript which describes a thorough assessments of the different prognostic approaches used in the grass pollen emission-source methodologies in their model (VGPEM1.0), applicable to Victoria, Australia. The publication also includes an excellent review of most of the relevant material on pollen emission modelling approaches to date, nicely summarising the limitations of regression versus statistical approaches. Whilst focussed on specific pollen type as might be expected and germane to this study region (Poaceaea) this is justified due to the significant health impacts, as highlighted by the thunderstorm induced asthma dispersal incident referenced, and the results produced are useful. The link to EVI is also useful. As discussed in section 3 of their manuscript the modelling approach does not include some of the more detailed mechanisms associated with pollen emission, that may impact pollen production and re-suspension etc. which may influence the variances discussed, but this is justified due to the lack of quantitative observational as well as modelling information for these mechanisms. The POD, FAR and ETS approach is well described although some context would be helpful.

Pollen types and sources can of course vary enormously across the globe but this work provides much needed evidence with good statistical analysis for different approaches and their applications to other regions and pollen types.

There will be many in the community who welcome this work as highlighting a growing need for pollen and other allergen/pathogen consideration in pollution modelling. In my opinion the manuscript is worthy of publication. Only very small changes are needed in order to clarify certain areas (for the non-pollen experts) with answers to minor questions to help support one or two sections with occasional reflection in the conclusions.

We thank reviewer #2 for these helpful suggestions to improve the manuscript and make it clearer.

Comments

1. There a couple of other studies that might be worth referencing to place this work in a more global context, e.g. Lake et al. (2017),and Pasken and Pietrowitz.

Lake et al (2017) estimated the number of Europeans suffering allergic responses to ragweed by 2060 will more than double, due to climate change and the estimated spread of the plant. Climate change could prolong the pollen season, changing the pattern of exposure.

Pasken and Pietrowitz (2005) make short-term forecasts of oak pollen in Missouri, USA, finding that the accuracy of the meteorological data was crucial in tandem with an understanding of pollen release biology.

Add text to page 2 line 32. "An understanding of pollen release biology together with accurate meteorological data is crucial for pollen forecasting (Pasken and Pietrowitz, 2005)."

Add text to page 2 line 33. "Indeed, climate induced spread of ragweed is predicted to double the number of Europeans suffering allergic responses by 2060 (Lake et al, 2017)."

2. Section 2 Observations and characteristics of grass pollen. You list the pollen risk categories specific to Victoria/Australia. How do these factors relate to international risk factor league tables e.g. in the USA (where other factors such as Pollen and Overall national Capital Risk Factors for individual cities are produced or clinical risk factors in the EU usually in terms of grains per year, e.g. Agnew et al. 2018, Int J Environ Res Public Health).

This comment relates to analysis comment 2 reviewer #1 posed on international pollen classifications. In terms of pollen forecasting having a daily risk classification is crucial. Agnew et al (2018) look at allergic sensitization and disease in children, and relate the impacts to the number of ragweed pollen grains counted per year. Children living in high pollen areas (>5000 grains m^{-3} $year^{-1}$) were more at risk than those living in low pollen regions (<400 grains m^{-3} $year^{-1}$), though the study found that children brought up in rural areas had more resistance than city dwellers.

The Asthma Capital Risk Factors report lists cities in terms of eight contributing factors, pollen being one of them. It is not just about pollen (https://www.aafa.org/media/2119/aafa-2018-asthma-capitals-report.pdf).

Text added to page 4 line 15. "The Australian grass count categories are similar to those used in the UK and Europe at the low and medium count categories, but the Australian extreme category is reached at pollen counts up to 3 times lower than Europe and the US (Zink et al., 2013; Osborne et al., 2017; US National Allergy Bureau)."

Add text to page 4 line 15. "Whilst epidemiological studies commonly use annual pollen totals, we use a daily pollen risk classification system because we aim to predict daily pollen concentrations."

3. Section 3.1.6 Statistical Models. The limitation of the statistical models due to coarseness of the temporal training data (daily) is understood, however a sentence might be useful here explaining how this limitation is linked to the actual physical emission mechanism timescales via the gross timing function and day to day expected variation.

The statistical models are trained on daily data, and predict daily pollen concentrations when used at the BoM. However the C-CTM requires emissions at an hourly frequency and uses EVI data and hourly meteorological data to drive the emissions, therefore linking emissions to the day to day expected variation. The gross-timing function is meant to smooth out much of the day-to-day variation, and is modulated by the immediate-timing term when estimating variation in time in the emissions module.

Add text to page 9 line 27. "…thus cannot resolve higher-resolution temporal variation. The gross-timing function smooths out much of the day-to-day variation, and is modulated by the immediate-timing term when estimating temporal variability in the emissions module."

4. You show the non-linear relationships between VI, V2 model pollen responses and temperature, rainfall and relative humidity (Figure 4) – I assume the grayed areas represent the variances in each case? – So, can a brief sentence or two be included in this section to explain/summarise how these meteorological drivers actually physically relate to the pollen emission mechanisms please?

Add text to figure 4 caption. "The shaded regions correspond to ± twice the standard error of the GAM term."

Add text to page 10 line 25. “The shaded regions correspond to ± twice the standard error of the GAM term and are greater in regions of the distribution with fewer observations. For example, there were far fewer observations at the upper tail of the temperature range considered, and the standard errors are correspondingly larger.”

The second part of the question relates to analysis comment 1 from reviewer #1.

Replace text on page 10 line 27. “The statistical parameterisations were based on ambient pollen concentrations rather than emissions, and thus the non-linear terms take into account transport and dilution processes. The temperature response in both models increased until 25 to 30 °C. The decline in pollen response at higher temperatures is likely due to the dilution with a higher planetary boundary layer. Thus the assumption of declining emissions with increased temperature is likely incorrect. There is relatively little non-linearity with humidity. The general trend is for increased concentrations (or emissions) in drier conditions, explained by the drying required before anther dehiscence. The rainfall response shows a sharp decline until about 2 mm day^{-1}, after which little additional pollen suppression occurs, although there is considerable uncertainty given the relative paucity of high-rainfall days. The suppression of grass pollen concentrations (or emissions) is likely due to the low potential for anther dehiscence in moist conditions, and wet deposition of ambient pollen.”

5. How representative are these responses, especially temperature, for Australia generally and for this pollen type in particular? I am thinking of the study by Viner et al, 2010, as also pointed out by the Editor regarding the timing response.

Relates to editorial comment 5 of reviewer #1. Earlier Melbourne grass pollen GAM modelling by Erbas et al (2007) also found nonlinear terms for temperature, rainfall and RH.

Add text to page 10 line 29. “The shapes of these relationships are similar to those described by Erbas et al (2007) for grass pollen in Melbourne, and also by Zink et al (2013) for birch pollen in Europe.”

6. Can this statistical approach be robust enough to respond to inter-annual variations?

The statistical approach accounts for inter-annual variation via the EVI time-series at each grid-cell. Higher winter-time peak EVI values are associated with higher cumulative grass pollen counts over the following season. The EVI approach factors in the recent growing conditions (accounting for both temperature and rainfall); this approach appears to be reasonably effective for grass pollen in the Mediterranean style climate of SE Australia.

Add text to page 11 line 10. “The statistical approach accounts for inter-annual variation via the EVI time-series at each grid-cell. Higher winter-time peak EVI values are associated with higher cumulative grass pollen counts over the following season.”

7. How representative might these relationships shown in Figure 4 be with respect to interannual variation (will the EVI approach take this into account)?

We think the answer to this question relates to that given for the question 6.

The site at Melbourne is the longest running count site in Australia. Pollen data does extend back to the start of the 1990s but there are difficulties finding consistent satellite data at these earlier years to drive that component of the model.

We can see in figure 4 that the relationships for temperature and RH between V1 and V2 are similar. V2 is trained on one extra year at Melbourne and includes data from 7 additional sites than V1, yet the relationships do not change much – i.e., the peak in the temperature response for V1 and V2 are both ~0.5 and peak around 25-30°C, and there is a negative relationship with RH.

8. How do these dependencies, especially with temperature, compare to other pollen types described elsewhere in the literature as this obviously has implications for the risk factor analysis particularly if it is to be extended to other regions? A brief sentence on this might help with context.

At this stage we only propose to include grass pollen in an Australia wide model. It is expected that additional training data from other regions will be included at this stage. There are long time series of pollen counts in Sydney, Canberra, Brisbane and from sites in Tasmania. We know from these data that different seasonal timings will be introduced, as tropical grasses emit their pollen at different times of year (Beggs et al 2015).

Add text to conclusions, page 16 line 12 "Additional training data would be included to model pollen in other Australian regions, to account for the different seasonal flowering times of other grass species (e.g. C4 grasses) (Beggs et al. 2015)."

9. Page 13, line 6. You state that "Transport of pollen from the productive grasslands in the west of Victoria to Melbourne would rely on the U wind vector being modelled accurately, however the model lifetime of these pollen grains is 6 hours over a height of 1 km; too short for pollen emitted near Hamilton to reach Melbourne.`' You pose the initial question suggesting you will justify this but then ignore the point by assuming it is modeled correctly in order to justify the conclusion that these grasslands were not the source. Perhaps you could rephrase this sentence to make it less confusing?

U and V are modelled well when compared to AWS data (fig 5). Investigation of the pollen transport distances are relatively short, due to pollen size and density. Generally the pollen counted locally is predominantly determined by local grass coverage.

Add text to page 13 line 6 instead of existing sentence. "The observed U and V correlations are not strong however, and do not point to particular locations being strong pollen sources. Inverse modelling may help pinpoint productive grass pollen regions for each site."

10. Page 13, line 8. You state "We extracted the boundary layer height from the model (unavailable in the observations), which showed that the modelled grass pollen is more strongly correlated to atmospheric dilution (average r=0.61) than it is to temperature (average r=0.44). The model RH is more negatively correlated with grass pollen levels (average r=- 0.52) than is observed." Now going back now to Page 10, where you state that, "This decline in concentrations may be due to increased boundary layer heights (and thus greater effective dilution) rather than a decrease in emissions."

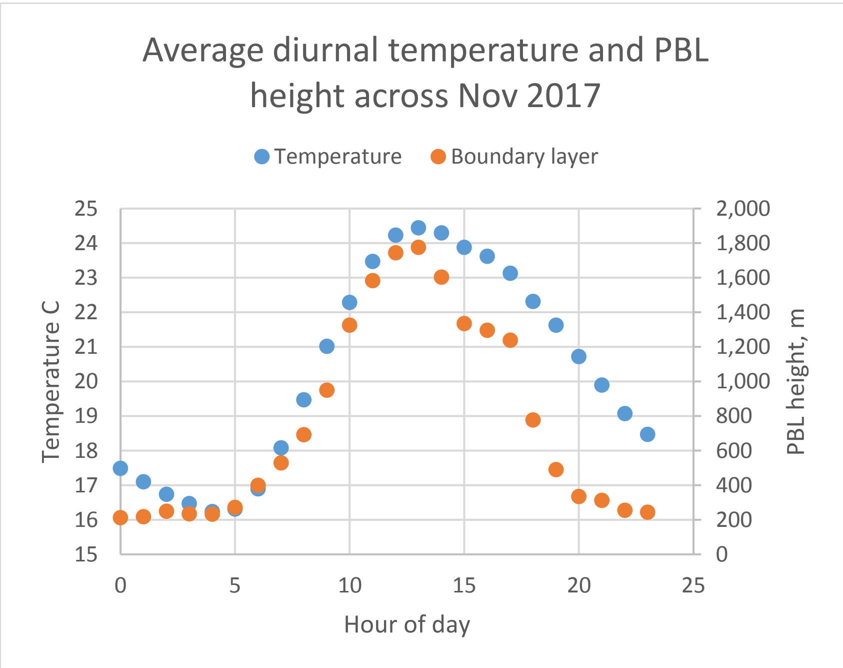
The latter statement I agree with but is this consistent with your statement about that a growing boundary layer depth is accompanied by a sharp drop in temperature – is this correct? Have I read this *correctly? One might expect that the concentrations are inversely related to the volume of air available for vertical mixing from the surface to the boundary layer top, or more precisely the mixed layer. So, increasing boundary layer height due to increasing convection during the day (and surface temperature)~ would lead to increased dilution due to turbulent mixing and dispersion in the lower boundary layer (unless in a zone impacted by strong recirculation from convective outflow or topographic influence). I believe this is generally observed in Melbourne. A drop in temperature response does not seem consistent?*

The statement on page 10 talks about non-linear pollen emissions with temperature, and that pollen emissions decrease at temperatures in excess of 30°C (not the temperatures themselves decreasing). We think this drop in pollen emissions at high temperature is because of an increase in boundary layer height causing dilution. We adjust the sentence on page 10 line 28 to make this point clearer:

"The temperature response in both models increased until 25 to 30°C. The decline in pollen concentration at higher temperatures is likely due to the dilution with a higher planetary boundary layer (associated with higher temperature)."

As I understand it the impacts of summer versus winter boundary layer height development can significantly influence pollutant concentrations in Melbourne whilst the wind direction, e.g. from the local hills and vegetation sources in summer, influences the background tracer concentrations (Coutts et al. 2007, Atmos.Env.)? In addition sea-breezes can also be important in Melbourne and I understand the wind rose for Melbourne displays a very strong annual N-S bimodality with higher frequencies of average winds from the N but of course higher frequencies of much stronger winds from the ocean, S (BoM)?

Perhaps a sentence or two describing the known evolution of the boundary layer height with time of day in the measurement period specific to Melbourne would help put this section in context. It would also be useful for the general readers (even if only by reference to previous work. I note you state there were no contemporaneous observations)?



There are no coincident observations of boundary layer height, and it is not routinely measured by the BoM. The Coutts et al (2007) paper only describes CO2 fluxes and not how the Melbourne boundary layer evolves. I have extracted the boundary layer height variable from the ACCESS model and plotted a diurnal average across November 2017.

Add text to page 13 line 10. “Average modelled diurnal boundary layer evolution during November 2017 in Melbourne is to increase after sunrise at 05:00 (AEST) to a peak of 1780 m at 13:00. The height begins to decline during the afternoon coincident with a southerly seabreeze, but is still above 1200 m at 17:00. The nocturnal boundary layer is around 200 m.”

Although it is not necessary to reference this study the issue of significant variation of pollen concentrations with height may need to be discussed here, e.g. see Damialis, et al. (2017), Nature Scientific Reports. The latter compares surface, tower and aircraft measured pollen concentrations with altitude.

Given what we know about the short model lifetime of pollen, we see 1-2 orders of magnitude decrease in pollen concentrations between the surface and 250 m. Damialis et al (2017) found most of their grass pollen at the ground level rather than aloft, corroborating our finding.

Add text where the boundary layer is discussed, “Over 77% of grass pollen is found at ground level (Damialis et al 2017) due to its size and density. The lifetime of our model pollen over 1 km is 6 hours.”

11. Perhaps you could include a brief summary of the wind climatology (your U and V components) as this is central to predicting wind pollinated species. This would also be helpful to place your wind thresholds in context, especially in terms of how these contribute to emission mechanisms and the correlation (or lack thereof`) you observe with these thresholds.

Include text on page 12 line 29. “We include a wind rose for each AWS site in the supplementary section to determine the strength of the U winds. The roses show a strong southerly influence, corresponding with the afternoon sea breeze at most sites apart from Churchill, located within an east-west aligned valley. Sites further west in Victoria (Hamilton and Creswick) also show a strong northerly influence, generally with a greater percentage of wind speeds above 4 m s^{-1} than elsewhere.”

12. Section 5 Conclusions. How do your conclusions regarding the wind and RH correlations in particular compare with European and US studies?

Sofiev et al (2013, fig 4) also show observed pollen being negatively correlated with RH, and has very little correlation with observed wind speed. The reason for the low correlation with wind speed is “the result of two competitive effects. The stronger wind speed increases the emission rate but also improves ventilation and promotes turbulent mixing”.

Would be better placed in the results discussion. Page 13 line 24. “Sofiev et al (2013) also show observed birch pollen in Europe being negatively correlated with RH, and has very little correlation with observed wind speed, due to the competing effects of strength versus increased ventilation and mixing.”

13. Would it be helpful to include a statement concerning how much variation the smoothed statistical approach potentially might miss over and above the seasonal maxima?

Move text from page 14 lines 4-7 to bottom of page 13 (keeps E10 discussion together). Include the following text: “Both the statistical emission parameterisations assume an underlying Cauchy distribution, which is modulated by the effects of wind, temperature, humidity and rainfall. At each model grid-cell, the peak and magnitude of this bell curve is calculated from statistics inferred from the EVI gradient.”

Rewrite text on page 16 line 9. “The smoothed statistics for E10 used 16 years of observational data from the UoM and one year from the seven other Victorian sites. The smoothed statistical approach is modulated by the hourly effects of wind, temperature, RH and rainfall, which introduces temporal variation. The EVI also varies spatially and temporally, meaning that this method is suitable for future years and for other regions of Australia.”

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