We thank the Anonymous Referee #3 and Editor Paul Stoy for their helpful and constructive comments on the earlier draft of our manuscript. We have revised our manuscript to address these comments, and have included notes on these revisions below (in italics).

Anonymous Referee #3

As you show that spruce cones retain viable seeds throughout fire, doesn't that by definition mean that spruce is serotinous, and the issue is that is has been thus far, been misclassified? What is the differences between a "true" serotinous strategy (what the other species listed by you in the same ecosystem are doing) and what you show that the spruce is doing?

Serotiny refers to a "banking" or retention of multiple seed cohorts by a parent plant. White spruce is non-serotinous, as cone opening occurs immediately after seed maturity and multiple seed cohorts are not retained in the crown. Although our results do show that cones may contain viable seed during fire, we note that fire is only one of many mechanisms that can open serotinous cones (pyriscence), and fire isn't a necessary condition for defining serotiny (see review by Lamont et al. 1991). We have added lines 34-35 to clarify this.

The CFD simulations are at a much larger scale (0.5m2, P16714, L7) than a cone. They therefore, assuming the model is perfectly parameterized and that all the intensive list of parameters and assumptions about fuel, fire and tree structure are perfect, can at best, provide an estimate to the mean temperature and radiation forcing during a fire. There is a huge variability of these conditions during fire, in different locations in an active fire and between different fires, I do not think that the small number of cases that was simulated here could represent the actual range of common conditions.

The simulations were used to provide theoretical evidence that seeds can survive forest fires, not to characterize the entire range of variability in fire behavior that might be experienced by this species. Demonstrating how well WFDS represents the spectrum of variability of fire behavior in this context is beyond the scope of the manuscript. We have revised lines 93-96 to clarify this.

But even if we leave that alone and restrict ourselves to the range provided by these simulations, there is large variability of convective heat due to air-flow and turbulence patterns around the code and the branch-leaf cluster that surround the cone. None of it is resolved by the FDS model given the resolution used here. Even for cylindrical or spherical objects, lee-side eddies tap heat and provide strong and uneven eating at the downwind side of the object during a fire.

We agree with the referee that this fine-scale turbulence is not resolved in our simulations. However, we argue here that this level of resolution is unnecessary for the situations considered here (also see below). The referee is correct that eddies can increase leeward Nusselt numbers

Nu (convection heat transfer coefficients) on cylinders, but only for very high Reynolds numbers Re (roughly Re ≥ 140000; Giedt 1949). However, the small diameter white spruce cones have little effect on leeward flow patterns (Re) and are not expected to increase leeward Nu sufficiently to cause uneven heating around the cone. Indeed, back-of-the-envelope calculations assuming a gas temperature of 1325 °C (adiabatic flame temperature of forest fuels; Drysdale 1999) suggest that enhanced leeward heating would only occur for gas velocities greater than 2740 m/s, a value that is orders of magnitude larger than would be experienced in a forest fire. The uniformity of boundary layer development and consequent convective fluxes, along with the high length-to-radius ratio of cones, mean that the one-dimensional model and assumptions are appropriate for spruce cones in fires. We have revised lines 114-117 and have added a citation to data of Giedt (1949).

The details are therefore lost, and while still providing important information, the value of these super-detailed simulations is somewhat diminished given the scale mismatch between the simulations and the scale of the actual processes that are critical for the heat distribution within the cone.

With respect to the referee's comment that the simulations are not sufficiently realistic because the cones are too small compared to the grid cell size, we have added new analyses (lines 254-262 and Appendix C) to show that the computational grids are sufficiently resolved for the cone heating considered in the MS (and actually the grid resolutions are much finer than is necessary for the cone heating model). The issue here has two aspects. The cone temperature history is the result of (1) the total incident heat flux from the fire plume and (2) its response to the net heat flux based on its material and geometric properties. Because the cone is thermally thick, it does not respond to higher frequency fluctuations in the total incident heat flux. This means that a certain degree of variability (i.e., characterized by the higher frequency oscillation of the total incident heat flux) in the fire doesn't matter – the total incident heat flux changes too rapidly for the cone to respond. The question is then: given the grid cell size, does WFDS retain enough of the variability of total incident heat flux that is relevant to the cone's response? To address this question, we modeled the cone's response to prescribed sinusoidal heat fluxes characterized by different frequencies, and showed that seed temperature does not respond to oscillations of the prescribed heat flux with frequencies that are half or double those present in our simulations. As the cone does not respond to changes in these flux frequencies, then it would not matter if the simulations were run at a much higher grid resolution (capturing all the physics that the referee is concerned about) as the cone heating and seed temperatures simply would not respond to these higher frequencies.

My most critical point is that there were no empirical observations and no attempt to evaluate the heat transfer model. It is rather straight forward to heat some cones and test whether the model predictions of maximal seed temperatures are in any way close to reality. The large number of parameters that control heat transfer where mostly based on other published data that I doubt was directly applicable to white spruce cones in wildfire condition. Also, the super simplistic assumed structure of the cone is rather far from real. The cones have cracks that lead to the seeds and sub-millimeter differences in the width of these cracks may lead to very large differences in the amount of heat that is advected inward. Given this rather large leap of faith between the parameter and setup of the heat transfer simulation and a realistic cone, some evaluation of whether the model is even in the ball park is critically needed. Given the CFD model resolution and assumption this can be conducted in a furnace, given constant temperature and uniform heat distribution, and while not very realistic it would be consistent with the rest of the data and would still produce an important insight into the applicability of the model. I would recommend testing cones from different stages of maturation, because I suspect that the cone properties change with time.

We agree that validation of the one-dimensional conduction model would be straightforward and would strengthen our results. It would be possible for us to conduct evaluation experiments, but a major obstacle at this time is that we do not have any cones for the experiments. Cones would not be available until mid-summer, and even then cone availability is uncertain as white spruce is a masting species that only produces large numbers of cones roughly every 7-10 years. We wonder if it is worth delaying publication for data that may or may not be attainable in another several months (or years).

With respect to our use of a one-dimensional conduction model and thermal property estimates from the literature, we should like to note that we used a modelling approach to provide theoretical evidence that cones can survive fire. Models are approximations. We approximated white spruce cones as cylinders, with physical properties that we measured from white spruce cones, and thermal properties obtained from the literature for cone constituents like water, char, etc. (as is routinely done in the engineering literature). As we discuss above and in the manuscript, the Re and length:diameter criteria justify our use of a one-dimensional cylindrical model (this can also be found in any introductory heat transfer text, e.g. Incropera et al. 2006). Furthermore, a one-dimensional conduction model has previously been applied to heating of woody fruits in fire (Mercer et al. 1994), an even simpler lumped capacitance model has been applied to heating of Pinus *cones (Johnson and Gutsell 1994). Additionally, as can be observed in our Figure 1, the scales of closed cones are tightly sealed and there are no air spaces that would permit convection towards the cone center (we have added lines 117-120 to clarify this). Like all models, this one-dimensional conduction model is an approximation and may not be a perfect representation of a white spruce cone, but we believe that it is sufficient for providing a theoretical estimate of seed survival in fires.*

The referee is correct that cone properties vary through time. To describe this variation, we made weekly cone collections to estimate thermophysical properties, and used a sensitivity *analysis (Fig. A1, Lines 153-179 and 223 – 227) to show that variation in thermophysical properties causes less than 10% difference in maximum seed temperature.*

Minor comments: P16706 L9 – the (Navier–Stokes) is not appropriate here, it I not the name of the model used but the governing equation in the general theory behind fluid dynamics. What was the actual cell size (you only provide an abstract equation) of the heat transfer model? What was the timestep of the CFD and heat transfer models? Are the thermal parameters in table 1 that are taken from previous publications specific to spruce cones, or are they general to wood/bark of that (other?) species?

We removed "(Navier-Stokes)" from line 22. The spacing of nodes for the cone heat transfer model was added to lines 429-430. Time step information was added to lines 427-429. The literature values in Table 1 are not specific to spruce cones, but are instead basic handbook-type values for cone constituents such as char, water, cellulose, etc.; details of this parameterization were added to lines 239-249.

P. Stoy (Referee) paul.stoy@montana.edu

This review follows from a conversation that I had with the Anonymous Referee regarding the study and reflects our common concerns. I would be preferred if the authors quantify the heat transfer coefficients of the cone(s) in an oven to account for and/or clarify the assumptions made in the manuscript. The concern is largely that the structure of the cone may result in more efficient heat transfer than a cylinder. It was even suggested that the exercise could be somewhat enjoyable, and would certainly help solidify the experimental findings regarding serotiny. The additional study need not add excessive length to the manuscript and could be introduced as a sensitivity analysis on the assumptions regarding cone heat transfer.

As mentioned above, we agree that validation of the one-dimensional conduction model would strengthen our results. We would be willing to conduct these experiments if they are necessary for publication, but we do not presently have any cones for these experiments and are not certain that we would be able to obtain any this summer. We are however confident in our application of the one-dimensional conduction model, as discussed above and further clarified in the manuscript text.