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Interactive comment on "Forecasting temperate alpine glacier survival from accumulation zone observations" *by* M. S. Pelto

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The referee comments indicate aspects of the paper that are inadequately discussed and arguments not clearly put. This input will be invaluable in making this paper a useful contribution. I accept all of the suggestions made. I disagree with two of the comments discussed in some detail below, while recognizing that both of these points could likely have been avoided if the text had more completely addressed the key issue. First two points of clarification. The survival forecast proposed does not attempt to provide timing for glacier disappearance, that would be the second step after the argument for the first step has been made. Trying to accomplish both in the same paper is too much to cover either adequately. The forecast model is based on temperate alpine glaciers that are less than 10km2 in area and cannot be applied to ice caps and

outlet glaciers.

Referee Comment: "While the paper is generally well written, there is a disconnect between what the paper promises (forecasting temperate alpine glacier survival) and what the paper actually delivers (a description of features apparent in the field and on remotely-sensed imagery that indicate a glacier is experiencing negative mass balance). . ...An example of this transient behavior is the initial adjustment of glaciers to the end of the Little Ice Age. Much of the non-equilibrium changes the author describes for the glaciers in the Cascades and Wind River Range undoubtedly occurred for these same glaciers at the end of the Little Ice Age. Yet, the glaciers continued to survive and they largely equilibrated with climate during the period 1945-1977. Thus, they adjusted their accumulation areas to reflect a geometry that was better suited for climate during the 20th century."

The forecast of glacier survival is quite distinct from that of negative mass balance. An examination of glaciers similar to those examined in this study, i.e. Peyto Glacier, South Cascade Glacier, and their adjustment to post Little Ice Age conditions by Schwitter and Raymond (1993) noted glaciers experiencing substantial thinning at the terminus and minor thinning above the ELA, a steady state response, or as the referee called it transient behavior. This is not an adjustment of their accumulation areas to equilibrate to climate it is an adjustment of their ablation areas. Additional examples indicate that this pattern of limited accumulation zone change and large terminus area adjustment in the post Little Ice Age response is common. Figures 4-5 from Baumann and Winkler (2009) for Jotunheimen, Norway illustrate there is not a significant change in the accumulation zone margins from the Little Ice Age to present, but considerable terminus area change. The same point is evident in the mapping of glacier change for Garibaldi Provincial Park, BC (Koch et al., 2009), for most of the glaciers there is little change in accumulation zone margin today versus the Little Ice Age. An exception is Helm Glacier which appears to be disappearing. Altitude change at glacier heads was negligible relative to the terminus fluctuations for British Columbia in general from the Little Ice Age

(Schiefer et. al., 2007). Fremont Glacier in the Wind River Range (Naftz et al.,2002) was selected for ice coring because of the consistent accumulation zone extent since the Little Ice Age. Easton Glacier and Rainbow Glacier, Mount Baker (Harper, 1993) notes the lack of change in the accumulation zone margins from the Little Ice Age, while substantial retreat occurred. Each of these are observations based on glaciers that were at the time experiencing an equilibrium response to climate change. Thus, in response to the post Little Ice Age climate change it was the terminus region that experienced the bulk of the adjustment to climate change. The accumulation areas of these glaciers that did adjust to the post Little Ice Age climate did not change substantially. Both at the end of the Little Ice Age and today there are glaciers with marked changes in accumulation zone margins, these glaciers did not or are not experiencing a transient response to a new point of equilibrium, they did not equilibrate. For some glaciers the accumulation zone changes has been marked, and these glaciers have retreated without cessation and will likely disappear. These glaciers are the focus of a survival forecast.

This is an important distinction, there is a two track response to climate change for smaller alpine temperate glaciers, not a single track. The first track is dominantly ablation zone adjustment and survival. The second is both ablation zone and accumulation zone adjustment as well and disappearance. This is the important distinction that cannot be made without accumulation zone observation. This argument was not adequately made in the initial draft of the paper. A good example of the two track response and the difference that can be seen in accumulation response to a climate change is with adjacent glaciers in the Ortzal Alps Abermann et al., (2009) Figure 5. In this image the Rotmoosferner (RMF) and Wasserfallferner (WFF) Glaciers thickness changes and margins are shown for the 1997 to 2006 period. For WFF the change in thickness is insignificant in the accumulation zone and all marginal changes are near the terminus. For the RMF there is substantial thinning from the terminus up to and above the ELA, with new outcrops of rock emerging. The accumulation zone margin has receded as well in many locations. The change in thickness in the accumulation zone is markedly

less than the ablation zone, but significant. Will Rotmoosferner survive? Using the proposed model it will not. This example does indicate that the model as described, and noted by the referee, did not provide sufficient quantitative description of the magnitude of marginal change needed to warrant a forecast of disappearance. This will be addressed.

What I have observed is that glaciers with similar negative mass balances over the last 25 years can have either large changes in the accumulation zone or quite limited changes. The latter being the ones that are disappearing before my eyes, or in two cases did disappear. The survival forecast model is not accurately identifying glaciers with negative balance, since all of the glaciers examined have similarly large negative balances (Pelto, 2006). This point was not sufficiently addressed and will be the focus of analysis of the mass balance histories of the individual glaciers and their accumulation zone changes. The key idea here is distinguishing between glaciers that have negative mass balances, but little accumulation zone thinning and hence appear to be undergoing an equilibrium response to climate, and those that have significant accumulation zone thinning suggesting a disequilibrium (non-steady state) response. Thinning in the accumulation zone as identified by marginal accumulation zone recession and rock outcrop appearance cannot be forecast simply from the mass balance history.

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