**Alexandra Pulwicki MSc Thesis Defense – External Examiner Comments**

**JM Shea**

This thesis presents results and analyses of winter mass balance measurements on three glaciers in the Donjek Range, Yukon Territory. Field sampling methods and statistical interpolation techniques are explored in detail, and the thesis explores relations between mass balance measurements and topographic features (elevation, slope, aspect, exposure/wind redistribution, northness, distance from centerline, curvature), as well as other interpolation methods and

The main conclusions of this research include the following:

* Processes affecting winter mass balance vary from glacier to glacier. Interpolation schemes may not be transferrable between glaciers
* Multiple linear regression and Bayesian models of mass balance and topographic parameters yield similar results
* Linear interpolation models may result in overestimated mass balances but kriging models depend on sampling density and are not transferrable
* Snow density assumptions are a smaller source of uncertainty than interpolation method
* Monte carlo methods used to assess overall uncertainty in glacier wide mass balance
* A regional winter balance gradient (based on distance from topographic divide) exists 🡪 though questionable to combine datasets from different years and different types, e.g. point versus glacier wide mass balance

Overall, the thesis is extremely well-written – the scientific writing is lively and interesting, generally well-referenced, and free from typographical errors. I provide below a list of general questions/comments and specific comments, with reference to page and paragraph numbers.

**General questions/comments**

1. While your thesis deals with winter mass balance measurements, and there are interesting appendices on snow models and indirect snow accumulation methods, I am surprised that there is not more focus on existing glaciological observations. How is a net glacier mass balance value (Bw) typically measured/calculated? What range of vertical mass balance gradients have been observed in western North America, and how do these compare with your results?
2. One of your main conclusions is that a clear winter balance gradient exists in the region (Sec 6.3). This gradient is based on the distance from a topographic divide, which makes some sense, depending on the prevailing wind direction. But is it problematic that this relation is derived from different years and different types of data (pit versus glacier-wide MB)? What would you need to confirm this relation? I think an improved description of the datasets used (location, type) are needed here.
3. You mention in your conclusions that these are the results of only a single year of snow surveys. Would you expect similar relations to emerge if you had multiple years? Why or why not?
4. Your counterintuitive result for Sx and Glacier 4….Winstral et al. (2002) define an upwind direction based on local weather station data, and search for maximum correlations within a 60 degree window of that. What is the prevailing wind direction in winter? Shouldn’t your search window be narrowed around that direction?
   1. Why would Glacier 4 have different bw - topography relations than glaciers 2 and 13?
5. If you were in charge of setting up a mass balance program in the region, what sort of strategy would would you recommend? 10 years,
6. With the rich dataset that you’ve collected, have you explored how \*few\* mass balance measurements are required to estimate glacier wide mass balance (e.g. Fountain and Vechia, 1999)? What density of measurements do you think is needed?
7. Your estimates of errors in the mass balance measurements are often based on the SD of multiple measurements. What about error propagation: can you identify the source and magnitude of different errors and estimate the total observational error?
8. Have you examined the spatial correlations in snow depths for the individual glaciers (probably, as part of the kriging)? A comparison of semivariograms of distance versus correlation for point bw measurements might be interesting. (Underlying ice surface roughness leading to more heterogeneous snow depth measurements?)

**Specific Comments:**

Throughout: you should use standard notation for point winter balance measurements (*bw*) and glacier wide winter balance (*Bw)* . See Cogley et al. (2011) for details.

Piii: ‘results are consistent’ – which results?

P1p1: ‘frequent empirical measurements’ 🡪 do you mean frequent observations?

P1p2: ‘paramaterization’ (spelling, check throughout)

P2p5: ‘gradients in temperature from elevation changes’ = ‘vertical temperature gradients’?

Sec 1.3/1.4: I think some review here of standard glaciological mass balance measurements and assumptions would be useful. Is there a standard? How is mass balance usually calculated? A survey of observed mass balance gradients (dbw/dZ) in western North America would also be helpful

P11p3: Are there any glaciers that support vegetation?

P12p2: “large transects” 🡪 how large? Give specifics.

P12p3: “GRP” should be “GPR”

Sec 1.4: no discussion of use of UAV for measuring snow depth? As far as I know there are no published studies yet on winter balance determined from UAV, but there are numerous alpine snow studies

P36p1 and p4: at the top of the page you write that the Federal Sampler is ineffective in the accumulation area because the snow/firn transition can’t be detected. At the bottom you write that it *could* be detected. Which is it?

P42p1: 490 kg/m3 doesn’t seem too high

Figure 2.13: How many grid cells have zero measurements?

P45p3: 227-431 kg/m3 is given later, and shown in table 3.2

P51: a sage piece of advice from my PhD supervisor: “Relationships are between people. Relations are between variables.”

Figure 3.2: The disagreement between FS and SP density measurements deserves a longer discussion. Shouldn’t they be similar?

P91p4: check R2 values in Figure 5.1 versus text

P98p2: “WB on Glacier is” (missing glacier number!)

Figure 5.7: do the annotated numbers refer to glacier wide winter balance?

P115p2: In my opinion, the last line would be worth highlighting more in the abstract and the conclusions.

P140: 0 m w.e.?

Table 6.2: how do your uncertainties compare with other estimates (e.g. Zemp et al. 2009; Wagnon et al. 2013)

**References:**

Cogley, J.G., Hock, R., Rasmussen, L.A., Arendt, A.A., Bauder, A., Braithwaite, R.J., Jansson, P., Kaser, G., Möller, M., Nicholson, L. and Zemp, M., 2011. Glossary of glacier mass balance and related terms, IHP-VII technical documents in hydrology No. 86, IACS Contribution No. 2.

Fountain, A.G. and Vecchia, A., 1999. How many stakes are required to measure the mass balance of a glacier?. *Geografiska Annaler: Series A, Physical Geography*, *81*(4), pp.563-573.

Wagnon, P., Vincent, C., Arnaud, Y., Berthier, E., Vuillermoz, E., Gruber, S., Ménégoz, M., Gilbert, A., Dumont, M., Shea, J.M. and Stumm, D., 2013. Seasonal and annual mass balances of Mera and Pokalde glaciers (Nepal Himalaya) since 2007. *The Cryosphere*, *7*(6), pp.1769-1786.

Zemp, M., Hoelzle, M. and Haeberli, W., 2009. Six decades of glacier mass-balance observations: a review of the worldwide monitoring network. *Annals of Glaciology*, *50*(50), pp.101-111.