

Interactive comment on “Glacier annual balance measurement, prediction, forecasting and climate correlations, North Cascades, Washington 1984–2006” by M. S. Pelto

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The detailed comments by the anonymous referee are appreciated and will help clarify the paper, correct mistakes and enhance the results of the paper in a revised form. Below each point is addressed in turn, with the general comments addressed last. Author comments in quotes.

Specific Comments It is not apparent from the paper what distinction the author is making in the title between prediction and forecasting, which are nearly exact synonyms. "This paper is looking to identify a means to forecast glacier balance during not at the conclusion of the hydrologic/balance year. A prediction can be made before or after an event, whereas a forecast must be made in advance. In this case modeled might

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be a better word for the use of climate data to calculate annual balance. Of course this calculation cannot be made until after the balance year is complete and is not useful for forecasting" 18-10 The statement concerning 42 of 47 years needs to be explained here because the abstract mentions only 23 years, 1984-2006. "This paper utilizes the mass balance record of South Cascade Glacier (1960-2004), and the mass balance record of the North Cascade Glacier Climate Project (1984-2006), providing 47 years. Although since submission the South Cascade Glacier record has been extended through 2005."

18-23 It is not clear what has limited utility. "The accuracy is insufficient to be of value for either water resource managers or understanding the mass balance of a specific glacier."

19-22 Because the scope of the paper is 1984-2006, a more recent South Cascade Glacier report should be cited, namely Bidlake, et al. (2007) USGS Scientific Investigations Report 2007-8211;5055. "This just published report reached the author a week after this paper was submitted and has been utilized in this response and will in revisions."

20-11 Annual balance is not defined as change between successive mass minima. If NCGCP uses the fixed date method, that is annual balance and correctly is denoted by subscript a. "Annual balance is correctly defined in the preceding sentences of the manuscript, and in this sentence it should have said net balance instead of annual balance, as it is meant to distinguish the two."

21-6 The sentence implies that NCGCP finds net balance and USGS annual balance, whereas the opposite is true. "This will be clarified by switching the order."

22-17 It should be clarified that winter temperature is meant, not summer temperature, and how much of effect is shift of winter precipitation from snow to rain and how much is winter melting. "Winter will be added though it is not evident why anyone would consider summer temperature to have been the reference. It is not possible to quantify

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the amount of the impact due to rain versus winter melting, in part because the rain can also cause melting. What can be added is that the ratio between total precipitation (November-April) at local weather stations and April 1 SWE at five USDA Snotel sites has declined from 1.03 during the 1960-1976 period, to 0.90 from 1977-1995, to 0.85 from 1996-2007. This is indicating that less total winter precipitation is retained as snowpack. In recent years precipitation has been relatively high, but SWE has not."

22-23 Multiple linear regression should be used to obtain dependence on two independent variables, not the way Equation (1) is formed. 23-8 Bitz and Battisti (1999) found $r = -0.65$ between November-April PDO and South Cascade Glacier net balance, which gives 42 percent variance explained. Multiple linear regression has been used and the results presented by Pelto and Miller (2003). "The current equation was developed after both principle component analysis (PCA) and multiple linear regression yielded unsatisfactory results. Utilizing multiple linear regression does yield slightly more accurate results than the simple linear regression; however, it misses the point of this equation. The point of equation 1 was not to determine the most accurate equation for calculating glacier balance from climate data. The objective is to demonstrate how accurately it can be done using basic regional climate data. In addition, the equation is setup intentionally to mimic adding a calculated summer balance and winter balance value to yield an annual balance. Combining the two in multiple linear regression improves the r factors slightly, but it loses some of the ability to easily identify the seasonal data. That the simple linear regression equation works, signals that forecasting is possible, which was the goal. If the goal was strictly the most accurate equation, other models besides linear regression would be tested.

Multiple Linear Regression $ba = 7.03048 - 0.614959T + 2.219146s$ (1) SWE $r=0.85$, Summer temperature $r=-0.77$ Simple Linear Regression $ba = (2.5243s - 3.158) + (-0.772T + 12.016)$ (2) SWE $r=0.81$, Summer temperature $r=-0.71$

23-10 Sources of the PDO and ENSO data should be stated and if it was downloaded from an online site, also the date that it was. "PDO data is from

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<http://jisao.washington.edu/pdo/PDO.latest> from May 2007. ENSO data is from: <Http://www.cdc.noaa.gov/people/klaus.wolter/MEI/table.html> from May 2007."

25 Summary can be condensed: if Rule 2 holds, balance is non-negative (successful in 13 of 15 cases, 87 percent); if it does not hold, balance is non-positive (successful in 29 of 32 cases, 91 percent. "Good point this could be done although the specific cases still need to be listed."

25 Quantitative results should be given in addition to qualitative statements of the summary; that is, the two linear regressions of balance versus PDO and balance versus ENSO, as well as the multiple linear regression of balance versus PDO and ENSO. Scatter diagram Fig 8 suggests these regressions will explain very little of the variance in the balances. "The $r^2 = 0.045$ for PDO versus balance and is 0.278 for ENSO versus balance."

31 It needs to be explained why NCGCP values were not used for 1984- 1986; moreover, the 1986 value for South Cascade Glacier was -0.61, not -0.71. Most of the balance values for 1987-2005 are incorrect; those for 1993-2002 are exactly those for South Cascade Glacier, not the combined values, and others are not consistent with values in Table 2. "NCGCP values were used only in 2005 and 2006 otherwise data is from South Cascade Glacier, simply for continuity in derivation of the model. The forecast model will be compared to NCGCP data for the 1984-2006 period in this table in the revision. The data utilized for South Cascade Glacier was taken from Krimmel (2000) and Krimmel (2002) and WGMS data for years since. It is correctly noted by the referee that the data for the glacier has since been adjusted and Bidlake et al (2007) is the appropriate reference. As a caution many sources, such as Dyugeroev et al. (2002), have the same uncorrected values I utilized. Changing the data these values alters the predictive result for one year 1990."

38 Caption of Fig 7 should be revised regarding the range of years; it says 22 years 1984–2005 but 23 points are shown. "OK"

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18-3 Subscript a needed on b, here and throughout the paper. "It is noted as ba and the subscript is often not utilized in referring to annual balance ba or net balance bn."

20-3 Presumably >100 meant is meant. "Yes greater than 100 is meant."OK" 21-12 The sentence should end "...the high correlation (Table 3)."OK" 21-16 Variation from year to year is meant, not trend from year to year. "No trend is correct."

21-20 Least negative ba would be clearer than highest ba. "OK" 25 Rule 6 succeeds in 3 of 3 years. "OK" 26-2 Statement "error climbs appreciably" is unclear. "The equation for calculating annual balance from climate records does calculate the mean balance reasonably, however, if regression of the same climate data is applied to an individual glaciers annual balance record the accuracy declines."

29 Headnote should say..Annual balance of the 10 North Cascade... and net balancefor South Cascade.... It is net balance (not annual net balance) that is reported for South Cascade Glacier. It should be stated that South Cascade Glacier balances are in water equivalent meters, and the units for the other glaciers should also be stated. "OK, as previously noted corrected values for South Cascade Glacier net balance will be utilized."

29 Table 2 would be improved with an additional row showing multi-year mean values and an additional column showing multi-glacier means. "OK"

31 Headnote of Table 4 should say ± 0.2 to 0.2 for equilibrium and should cite section 5 instead of section 6. By the ± 0.2 , 0.2 rule 1962 should be classified as e, not p. "Table 4 will be adjusted to reflect both the updated values for South Cascade Glacier, and the efficacy versus NCGCP data in a separate column."

31 Balance values for South Cascade Glacier are published to two decimal places, and should not have trailing zeros deleted in Table 4. "OK" 31 Because South Cascade Glacier values are net balance and NCGCP values are annual balances, perhaps the column headings should be labeled just b, not bn. "OK" 32 Glacier codes should be

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deleted from Fig. 1 caption because their names are spelled out in the figure. "OK"

36 Caption of Fig 5 should indicate which years are represented. There are 21 points shown but Table 2 has 23 years. The dependent variable should be explicitly identified; is it the mean of the ten glaciers? 37 Caption of Fig 6 needs same attention as that of Fig 5. 39 Caption of Fig 8 needs same attention as that of Fig 5. It also should state the season over which the indices apply. The statement ...forecasting which demands less precision needs to be explained "Yes it is the mean of 10 glaciers. The complete climate data was available only through 2005. Captions will be adjusted."

There are many ungrammatical constructions, several involving the comma splice: "All seven noted will be changed as suggested."

General Comments

The paper describes a fairly accurate qualitative method for predicting glacier annual balance from October-April average of large-scale circulation indices PDO and ENSO. It does not clearly describe their quantitative utility, which is quite low. It mistakes the ENSO phase of El Nino as being positive.

"After years of attempting to accurately quantify glacier annual balance utilizing atmospheric indices, it seemed apparent this is for now a futile task. Several papers, including my own, have statistically derived the correlation between glacier balance and specific climate indices, but none have provided an accurate means of calculating annual balance. Further, if all we do is calculate mass balance after the hydrologic year is complete that is of glaciologic value, but not of water resource management value. It is necessary to forecast mass balance early in the calendar year to provide useful information to the water resource management community. The approach here was modeled on the National Hurricane Center forecasting approach, which looks at key leading variables. In this case we use PDO index and Multivariate ENSO index. The El Nino phase of the ENSO is positive, and the referee's reason for comment is unclear."

The paper constitutes publication of annual balance values over 1984–2006 for eight glaciers and over 1990–2006 for two others. The numerous errors and inconsistencies in the paper, as shown below, however, call into question the reliability of the mass balance values presented. Analytical methods are very weak. Equation (1) is not the correct way to determine the joint effect of two independent variables. Moreover, the data (Table 2) are eminently suitable for principal components analysis.

"This 23 year mass balance record has been published on numerous occasions as cited in this paper. This paper does not focus on the collection of this record or the reliability. The records high correlation with both the National Park Service mass balance in the North Cascades was noted in Pelto and Riedel (2001). The correlation is also evident with the South Cascade Glacier in this paper, and noted by Josberger et al., (2007). One hallmark of NCGCP is the publication of mass balance values for a given year by the end of that calendar year, much earlier than most. The data has been independently tested by other researchers such as, Bach (2002), in modeling efforts and found reliable. The long term mass balance record has been verified with longitudinal profiling on each glacier (Pelto, 2006). The author based on field measurements of NCGCP has pointed out errors in mass balance values obtained by another program in the North Cascades that were later corrected Riedel (pers. comm.). The mass balance values obtained from Easton Glacier have also proven vital to water resource modeling for the city of Bellingham, WA. Further the work by the author on Lemon Creek Glacier in compiling a 43 year record (Miller and Pelto (1999) has proved reliable when compared to long term glacier elevation change from radar profiling (Sapiano et al., 1997) and by climate modeling efforts by Tangborn (pers. comm.) and Dyugerov (pers. comm.) The only balance values in error noted are those from the South Cascade Glacier, which were taken from USGS sources, the recent adjustment is an important correction to make. The updated values will be utilized in the revision. The incorrect values for South Cascade Glacier remain in many important data reports. All of the above suggest that after 25 consecutive years of field mass balance work, the author is reliable in measuring glacier mass balance.

The data is suitable for principle component analysis was extensively explored and the results published by the author (Pelto and Miller, 2003). It was the failure of this method to yield a reliable method for calculating glacier balance from climate indices that led to exploration of forecasting. The indices are important impacting glacier balance at a macro scale, even if they do not explain enough of the variance to be useful at a micro scale for calculating specific glacier balance. The forecast presented here is simple and can be easily improved. This author is not an expert in climate indices or the formulation of advanced models for forecasting, and hence will leave that work to others. This paper is merely the first step in the forecasting process for glacier balance, not the last step, and that is how science advances one step at a time.

Equation 1 is not what the referee would like to see utilized, but it is an appropriate equation. The results suggest that this simple approach is not in fact weak, but yield robust results instead. Simple linear regression instead of multiple linear regression, provides a cleaner result for identifying the seasonal impacts, which were important in formulating the idea for forecasting. This needs to be emphasized in the revision. Further it highlights a key point that would otherwise be missed, that is though the two variables rely on data from different seasons, they are not independent in a real sense. If they were the forecasting method would not work as reliably. The conclusion that the analytic methods were weak ignore the whole point, the efficacy of the simple equations and what they tell us about the dependence-independence of the system."

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