Response to reviewers by Pearson et al.

Dear Review Committee,

We wish to thank you for your helpful comments and time spent reviewing our manuscript. We have implemented the suggested changes as recommended by the reviewers in this revised manuscript, with detail changes highlighted below. We also added clarifications to the limitations of our study with respect to open canopy vs. forested sites. Additionally, we agree that significant mid-season melt or rain-on-snow events have the potential to impact the location and elution of snowpack-based chemicals, and added statements discussing potential issues. Local SNOTEL data shows minimal midseason SWE losses, but without site specific temperature/soil moisture data we cannot distinguish between sublimation, melt, volatilization, or other chemical losses/conversions.

Please see the detailed list of edits below (**bold/italic typeface**).

Sincerely,

Christopher Pearson

Anonymous Referee #1

General comments:
This is a well constructed paper that provides a wealth of information on nutrient and Hg deposition to the Lake Tahoe watershed snow pack. It will be of interest to biogeochemists, snow scientists, and hydrologists. The paper is generally well written. I have identified a few typos and have a recommendation to change "snowpack" into "the snowpack" at multiple locations. The authors do this at some instances and not at others. The methods are well explained and the results and conclusions are strong. I recommend accepting this paper after minor reviews. Some of the comment I provide may
strengthen the work but they may be out of the bounds of what the authors wish to accomplish. The only strong suggestion I have is that the authors have to provide more information on how, when, and where rain on snow or thermal melt events could have affected their samples. Perhaps these events were not an issue at all- particularly if the melt events never made it to the bottom or out of the base of the snow. But I suspect they could play a role. For Hg or other species for which there is a focus on surface snow samples the potential for rain or melt events to affect snow pack concentrations is strong.

Specific comments keyed to the text:
Abstract
7: list the "chemicals"; **added N, P, and Hg.**

15: deposition and dynamics within the snowpack Here and in many other places I strongly recommend terming the snow pack "the snowpack" as if to say "the soil column", "the outcrop", "the organic surface layer", etc. In many places the authors do say "the snowpack" but in others they do not. I recommend being consistent and using "the snowpack"
We feel that the addition of "the" before snowpack makes reading awkward in some places, and include "the" at some places, but not others.

17: in the snowpack; **done.**

22: snow. Spatial; **done.**

26: the snowpack; **not changed.**

Introduction
p. 595
12: The Sierra Nevada; **not changed.**

23: The snowpack; **not changed.**

26: the developing;
27: , the snowpack Instead of "collects" perhaps use "receives" as "collects" might imply an active process while "receives" is passive? Somewhere in here perhaps just come out and say that "the seasonal snow pack is a spatial and temporal passive sampler of atmospherically derived particles, aerosols, and compounds"; **changed "collects" to "receives"**

p. 596
6: While the snowpack; **done**

19: the seasonal; **done.**

p. 597
8: the Sierra Nevada snowpack; **not changed.**

p.599
5-8: I understand why the sites were chosen as such. But how representative of the watershed is this? Ie how much of the snow pack is typically open, free of canopy, etc.?
A second way to ask: is the study missing potential physical, chemical or other processes that are common in the forested areas by only focusing on snow from the open areas? Since SWE is used later on to make basin scale calculations is the SWE in the open areas different than that of the forested areas? The forests likely have greater interception, lower albedo, shallower snow, and less wind effects on post deposition snow. These characteristics could affect photochemistry, and nutrient dynamics. A paragraph or at least a few lines explaining the potential limitations and presenting the % of area represented by the open snow pack could address this.

This is a good point. We clarified the limitations of using only open sites by adding the following statements: *"Canopy effects on total snow accumulation are incorporated in the SWE reconstruction model. However, measurements of deposition and chemical snowpack storage are based on canopy-free, open locations, and do not included effects of forest cover."*

In addition, we added the following statements in the discussion section in section 3.5:

"While canopy effects on total snow accumulation are incorporated in this estimate through the SWE reconstruction model, we did not include forest canopy effects on deposition and chemical dynamics as our snowpack measurements were limited to open, canopy-free locations. Deposition and snowpack dynamic processes in forests are known to show substantial differences compared to canopy-free locations, including increased dry deposition, throughfall deposition, or different photochemical processes (Poulain et al., 2007; Tarnay et al., 2002). In order to be able to compare different locations across the basin, we selected to not consider forest canopy locations and data on chemical dynamics, deposition, and storage are limited to open areas. The estimated deposition loads, therefore, are based on deposition and snowpack storage measured in canopy-free locations and could be different when effects of canopies and other forest processes were incorporated."

Tarnay, L.W., Gertler, A., Taylor, G.E., 2002. The use of inferential models for estimating nitric acid vapor deposition to semi-arid coniferous forests. Atmos Environ 36, 3277-3287.

I also wonder about the occurrence of rain on snow events and/or large thermal melt events that would affect surface snow SWE, potentially build percolation columns that would smear the surface snow signal downward, and, if the melt features reached the bottom of the snow pack, move nutrients out of the collected snowpack? Again perhaps some explanation of these events' occurrence, whether they are common or were encountered, and the likelihood that the melt events reached the bottom of the snow pack. **We added discussion sections to the possibility of these processes (see response below).**

p. 599
25: in the snowpack; **done.**

p. 600
3: a NADP; **done**

4: a glass. . .. . a glass. . .. . .. ; **done**

23/24: "in" is repeated twice in a row: **removed.**

p. 601 8: I think the "um" should be a "micron" symbol? ; **done**

21: The nitrate; **not changed.**

p. 604
5: Fig. 3a is referenced here. Fig. 2 has not been referenced yet.; **Order corrected in figures and text (i.e. switched Fig. 3 to Fig.2 and renumber text)**

Figs. 2 and 4: I recommend adding air temperature from the sites or locations nearby for the winter season. At the least, times when the air temperature was above 0C for more than 24 hours or was above 0C and a rain even occurred should be noted. I suspect that over the three years of the study there were some rain on snow events or melt events in the middle of the winter? Maybe not- I do not know. But it would be important to mention if they had occurred. This would be particularly important for Fig. 4 as some of the samples were at least collected after initiation of the spring melt. If the snow pack cores included the entire snow pack with little horizontal percolation or without the vertical percolation reaching the base of the snow pack.

For the Hg dynamics, for which the upper 10cm of the snow pack is deemed photochemical active and for which surface samples were employed the potential for melt events or rain in affecting Hg loading to the snow pack would be important. There are some studies showing an ionic pulse of nutrients, major ions, and Hg out of snow packs during spring melt (an “ionic pulse” to the base of the snow pack: Tranter et al., 1986; Bales et al., 1989; Harrington and Bales, 1998; Schuster et al., 2008).

Bales, R.C., Davis, R.E., Stanley, D.A. (1989) Ion elution through shallow homogeneous snow. Water Resources Research 25(8): 1869-1877.
Harrington, R., Bales, R.C. (1998) Interannual, seasonal, and spatial patterns of meltwater and solute fluxes in a seasonal snowpack. Water Resources Research 34(4): 823–831.
Schuster, P. F., J. B. Shanley, M. Marvin-Dipasquale, M. M. Reddy, G. R. Aiken, D. A. Roth, H. E. Tay-
lor, D. P. Krabbenhoft, and J. F. DeWild. "Mercury and organic carbon dynamics during runoff episodes from a northeastern USA watershed." Water, Air, and Soil Pollution 187, no. 1-4 (2008): 89-108.
Tranter, M., Brimblecombe, P., Davies, T.D., Vincent,C.E., Abrahams, P.W., Blackwood, I. (1986) The composition of snowfall, snowpack and meltwater in the Scottish highlands-evidence for preferential elution. Atmospheric Environment 20(3): 517-525.

Response:
We agree, and one limitation of our study indeed is a lack of (continuous) measurements of snowpack temperatures to assess mid-season melt events. We do, however, discuss effects of nutrient pluses during melt events that may contribute to observed patterns of nutrient storage and vertical distribution. We also revised the discussion sections relating to ionic pulses and potential early elution losses in section 3.2.1. as follows:
“Previous studies have observed parallel concentration declines of SO_4^{2-} and NO_3^--N during snowpack melt events due to similar early-season ionic pulses that lead to preferential losses of nutrients and other ions (Bales et al., 1989; Harrington and Bales, 1998; Tranter et al.,

1986). In support of such potential losses, Figure 4 shows decreasing snowpack NO_3^- concentrations in spring months, particularly in the second year, 2012-13, when sampling captured the beginning of the melt season. Preferential mobilization of solutes during melt events also has been shown to cause downward movement of solutes in the snowpack (Williams and Melack, 1991). Our vertical snow pit samples show highly variable distribution patterns with depth (Figure 6), which may indicate insufficient temporal resolution of pit sampling to detect vertical translocation. Similar early elution characteristics have been observed for NO_3^- and SO_4^{2-} (Stottlemyer and Rutkowski, 1990; Williams and Melack, 1991), and comparing volume-weighted seasonal wet deposition concentrations of SO_4^{2-} and snowpack $SO4^{2-}$ concentrations showed no large elution losses either (Figure 5). Our results suggest that Tahoe Basin snowpack NO_3^- is subject to multiple inputs and complex in snowpack processes, and that potential losses (such as during early ionic pulses) may be difficult to detect against additional surface (e.g., dry) deposition processes without very detailed time- and depth-resolved snowpack measurements."

Fig. 4: 2011-2012: Snowpack values for all N species are diluted by late winter storms. ; **done.**

p. 607
4: This is where elution is mentioned but its occurrence has not been established. ; **done.**

27: from the early; **done.**

p.608
9/10: in the late; **not changed.**

25: to the Tahoe; **not changed.**

p. 609
2: why the semicolon?; **changed to a comma**

7: in the snowpack**; not changed.**

15: to the snowpack; **not changed.**

p. 610
4: remove "very" as it is vague; **done**

13: in the snowpack; **done.**

14: in the snowpack; **not changed.**

17: our measurements do not allow; **done**

20: Arctic is misspelled; **done**

24: in the Sierra; **changed to Sierra Nevada.**

27: in the snowpack; **not changed.**

p. 611
13: site, also; **done**

p. 612
17: in the snowpack than in wet; **not changed.**

29: "in the Sierra" is vague. Sierra what? Nevada mountains?; **changed to Sierra Nevada**

p. 613 10: The Tahoe Basin snowpack; **done.**

15: the Tahoe snowpack; **not changed.**

18: Hg in the snowpack; **done.**

p.614
7: "with in" should be "within" ; **done.**

11: in the snowpack; **done.**

18-21: is there information presented on the deeper, denser snow pack? Particularly in light of potential melt events at some elevations? And with respect to potential for bigger storm events at the higher elevation sites due to orographic effects. She Hg versus SWE relationship: is that only for surface snow layers or the overall snowpack?
We clarified that the relationships between Hg and SWE are for overall snowpack, and not for surface snow layers. We also added vertical patterns of Hg (both DHg and THg) of the three pits samples to Figure 6 in order to further discuss vertical patterns. We clarified this discussion section as follows:
"Evidence for surface-based photochemical losses of Hg are lower concentrations of Hg in upper snowpack layers (Figure 6). Declines in Hg concentrations between cumulative wet deposition and integrated snowpack content were mainly drive by DHg, with up to 4.5 times lower concentrations observed in integrated snow pit samples than volume weighted wet deposition (Figure 5). Aside from photochemical losses, it is possible that vertical patterns are co-determined by vertical movement and solute transport of Hg. Previous studies have reported Hg pulses in runoff during snowmelt events (Schuster et al., 2008; Stottlemyer and Rutkowski, 1990). In addition, sorption processes could lead to conversion between DHg and particulate Hg and changes snowpack Hg speciation."
p. 615
7: storage, an increase; **done**

p. 616 12-13: much of the snowpack; **not changed.**

p. 618
6: in the snowpack; **done.**

13: how about “more than” instead of “over”; **done**

20/21: in the Lake Tahoe Basin; **not changed.**

p. 620
6: in the Lake Tahoe; **done.**

9: the Tahoe snowpack; **not changed.**

12: that the Lake Tahoe basin; **not changed.**

Fig 7. Potential for melt events to be represented or to have affected the snow chemistry? **done.**

Additional changes:

Figures 5 and 6 had incorrect unit values on the nutrient concentration axis. Corrected figures are now included.

Minimum and maximum concentrations for snowpack Organic N (listed in section 3.2.3) were found to be incorrect. Concentration values were corrected:
“Integrated snowpack organic N concentrations ranged from BDL (below detection limit) to 211 ug L^{-1} in 2011-12 (n=49 cores), BDL to 253 ug L^{-1} in 2012-13 (n=56 cores), and 120 to 260 ug L^{-1} in 2013-14 (n=3 integrated snow pit).”

Revised Figures 5 and 6 below:

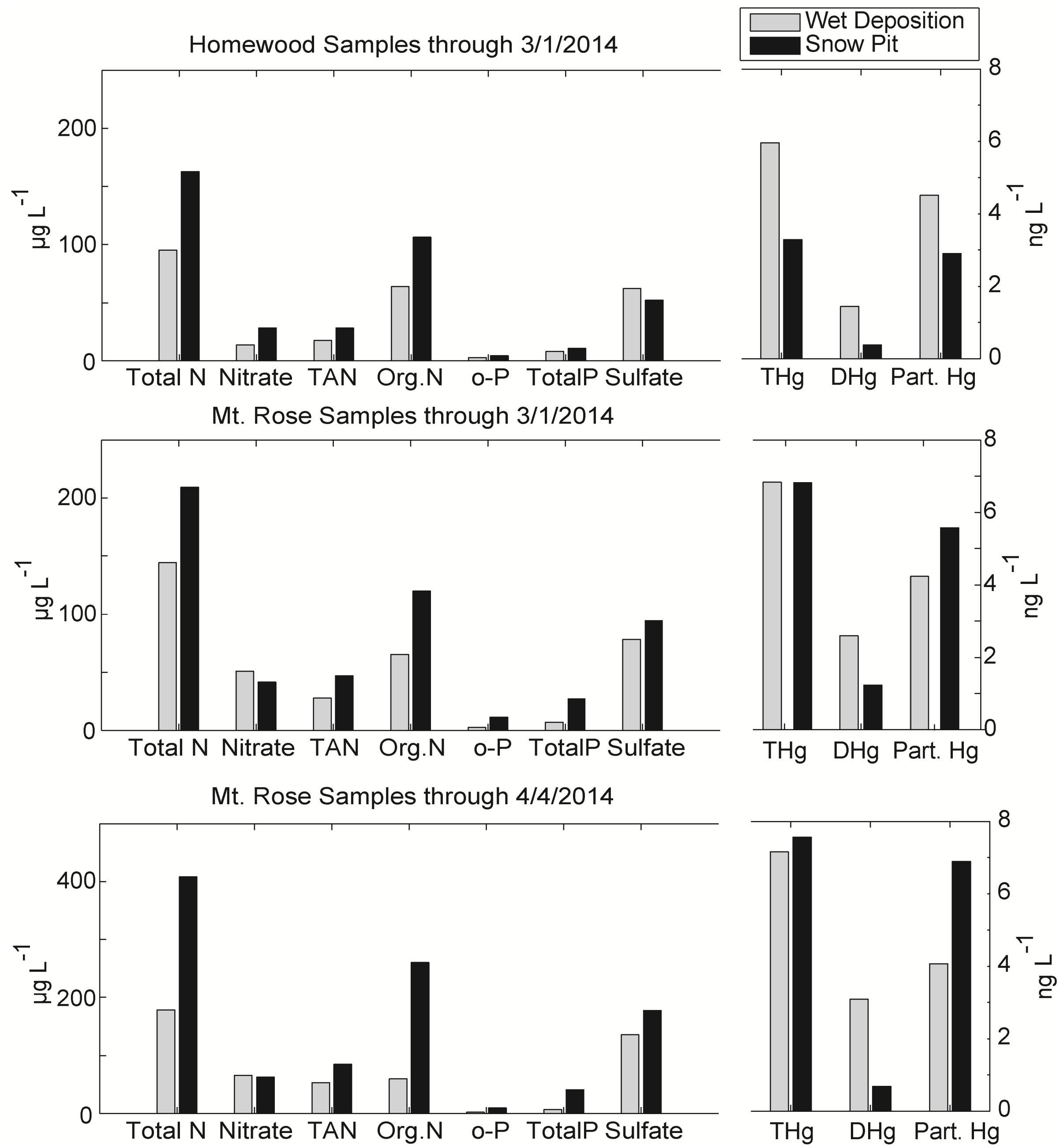

Figure 5: Comparison of seasonal average volume-weighted wet deposition concentrations with integrated snow pit samples from the 2013-14 snow year.

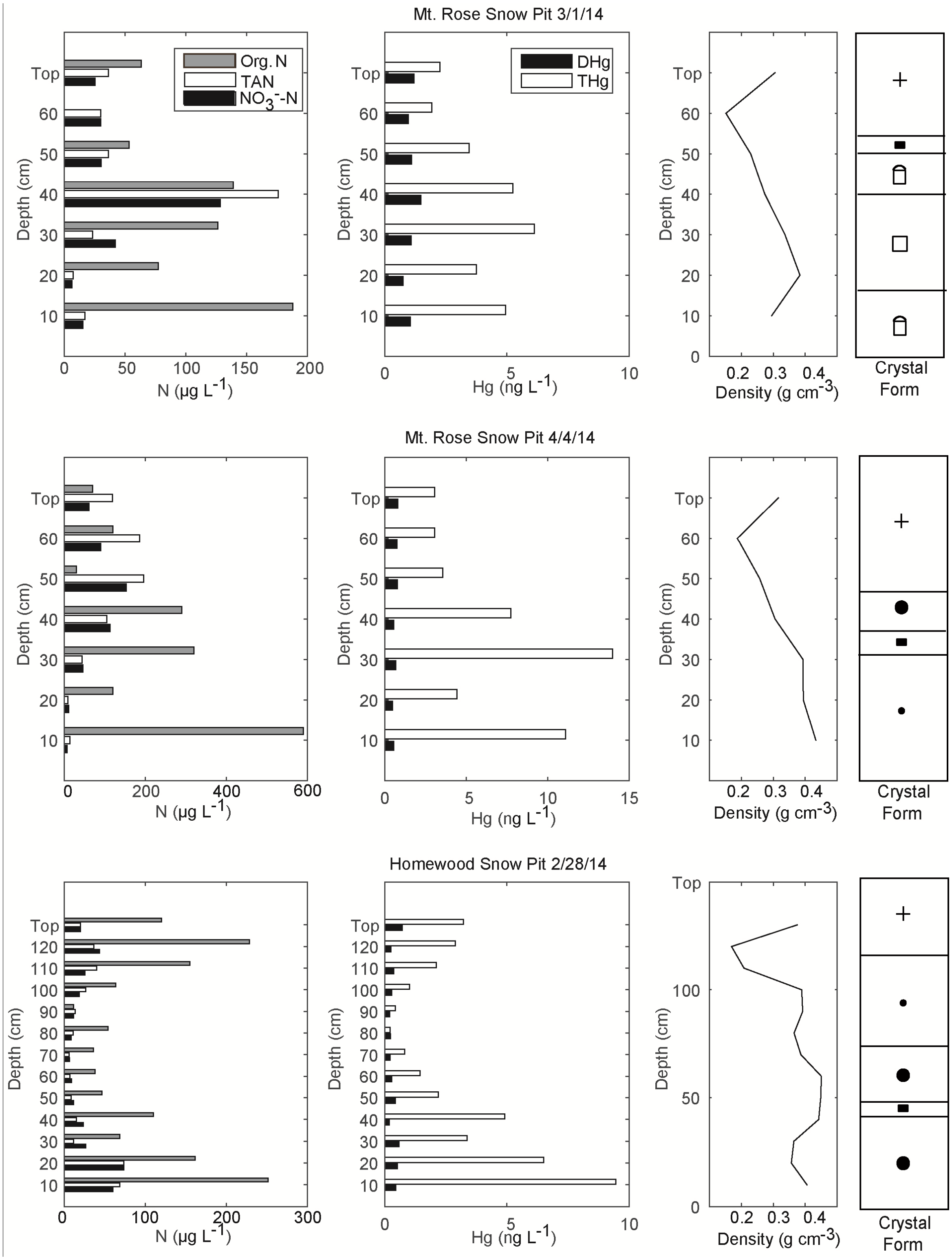

Figure 6: 2013-14 snow pit profiles for nitrogen and mercury species concentrations, snow density, and crystal form. Crystal classifications are based on the ICSI classification for seasonal snow on the ground (Fierz, 2009).