From: Hilary Eisen
To: FS-comments-pacificsouthwest-stanislaus; Jim Gibson; Wilkinson, Kathryn K -FS
Subject: OSV
Date: Tuesday, October 9, 2018 10:28:42 AM
Attachments: Stanislaus_DEIS_comments.pdf
Attachment 2_STF_Important_Non-Motorized_Recreation_Areas.zip
Attachment 3_Designated_OSV_Routes.zip
Attachment 5_Hatchett and Eisen 2018.pdf
Attachment 6.pdf
Attachment 4_Hatchett et al 2017.pdf
Attachment 1 - Maps.pdf

Dear OSV planning team,

Comments from Winter Wildlands Alliance and Snowlands Network concerning the OSV designation project DEIS are attached. There are 7 items attached to this email:
1) Stanislaus_DEIS_comments.pdf
2) Attachment 1 - Maps.pdf
3) Attachment 2_STF_Important_Non-Motorized_Recreation_Areas zip file
4) Attachment 3_Designated_OSV_Routes zip file
5) Attachment 4_Hatchett et al 2017.pdf
6) Attachment 5_Hatchett and Eisen 2018.pdf
7) Attachment 6.pdf

Please contact me if you are unable to download any of the attached documents. I would be happy to provide a hard copy, or files on a USB drive, upon request.

thank you,
Hilary Eisen

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Hilary Eisen
Policy Director
Winter Wildlands Alliance
P.O. Box 631
Bozeman, MT 59771
(208) 629-1986
donate today to help keep winter wild!

October 9, 2018

Jason Kuiken, Forest Supervisor
Stanislaus National Forest
Attn: Over-Snow Vehicle Use Designation
19777 Greenley Road
Sonora, CA 95370

Submitted via email to comments-pacificsouthwest-Stanislaus@fs.fed.us

Re: OSV

Dear Forest Supervisor Kuiken,

Please accept these comments on behalf of Winter Wildlands Alliance and Snowlands Network on the Draft Environmental Impact Statement (DEIS) for the Stanislaus National Forest Over-Snow Vehicle (OSV) Use Designation. Winter Wildlands Alliance (WWA) is a national nonprofit organization dedicated to promoting and preserving winter wildlands and a quality human-powered snowsports experience on public lands. WWA represents over 50,000 members and 41 grassroots partner organizations in 16 states, including Snowlands Network. Snowlands Network is a membership-based organization that advocates for non-motorized backcountry winter recreation. Snowlands and WWA members often visit Stanislaus National Forest (STF) in the winter and spring seeking opportunities for winter recreation in quiet, non-motorized, conflict-free environments. Members of both organizations will be significantly affected by the OSV Use Designation decision.

Our organizations, together with the Center for Biological Diversity, were plaintiffs in the lawsuit that instigated the OSV planning effort, and we obtained the right in the Settlement Agreement to submit an alternative to be considered in the analysis. Our alternative, submitted August 3, 2015, has been incorporated in the DEIS as the basis for Alternative 3.

SUMMARY

We strongly support Alternative 3 as being the only alternative analyzed in the DEIS that complies with the Travel Rule requirement to minimize conflicts between motorized and non-motorized recreation. Alternative 5, the Preferred Alternative, is unacceptable because 1) it does not address the full impact of snowmobiles on non-motorized recreation, and 2) it designates portions of existing Near Natural Areas for OSV use. Alternative 5 would be acceptable if it were modified such that several important non-motorized recreation areas and all portions of existing Near Natural areas were not designated for OSV use.

Recommendations

The following recommendations summarize the actions we feel are necessary to adopt in the Final Decision to comply fully with NEPA and Travel Rule requirements.

- Do not designate for OSV use any of the areas described in the section "Important human-powered winter recreation areas" starting on page 5, with the possible exception of the Mattley Ridge and Herring Creek areas.
- Only allow OSV use within Mattley Ridge and Herring Creek backcountry ski areas when the major OSV access points in their respective areas are closed due to spring plowing.
- Do not designate for OSV use any portion of the existing Near Natural Areas, Recommended Wilderness Areas, or Special Interest Areas, or reduce any of these areas in size by amending the current Forest Plan.
- Do not designate low elevation areas (below 5,000 feet, and the Interface Area) for OSV use.
- Mandate a minimum snow depth of 12 inches for OSV travel on the forest, with greater depth restrictions in Stanislaus Meadow and Highland Lakes (24 inches), and in areas with soils that are particularly prone to compaction (18 inches).
- Set an OSV use season of December 1 – April 30 for most areas of the forest and in sensitive wildlife areas.
- Designate Highway 108 as a PCT crossing point. Do not designate other areas adjacent to the PCT for OSV use.
- Make thoughtful designations based on quality of experience and minimization criteria rather than numbers of acres open or closed for OSV use.
- Incorporate adaptive management into the travel plan so that the plan is flexible and responsive to "abnormal" winters and snow conditions.

These recommendations are explained in detail in the paragraphs that follow.

GOVERNING REGULATIONS

The OSV Use Designation project is governed by the National Environmental Policy Act (NEPA) and the 2015 Travel Rule.

NEPA Requirements

NEPA requires that the "*EIS shall document the examination of reasonable alternatives to the proposed action*."[1] When we submitted our Alternative in 2015 we provided an in-depth explanation of specific concerns related to OSV use on the STF as well as details on a handful of areas that are extremely important to the non-motorized winter recreation community. These areas must not be designated for OSV use if the Forest Service is to minimize conflict between OSV use and other winter recreation use. Although we appreciate that our Alternative has largely been incorporated as Alternative 3, the DEIS lacks an analysis and discussion that puts Alternative 3 in context. For example, there is no mention in the DEIS of specific areas that are important for the non-motorized winter recreation community, much less any acknowledgement that Alternative 3 is the *only* alternative that would not designate these areas for OSV use.

[1] 36 CFR Section 220.5(e)

Travel Management Rule

In 2015, the Forest Service's Washington Office released the Over-Snow Vehicle Rule providing a framework for winter travel planning efforts on all National Forest lands.[2] The OSV Rule requires that forests designate routes and areas where OSV use is allowed, publish these designations on an OSV use map, and prohibit any OSV activity that is inconsistent with the published map. The STF is in the midst of this OSV designation process and is among the first forests in the nation to implement the OSV Rule.

The OSV Rule requires national forests with adequate snowfall to designate and display on an "over-snow vehicle use map" specific areas and routes where OSV use is permitted based on resource protection needs and other recreational uses. The STF is obligated to comply with the minimization criteria outlined in Executive Order No. 11,644, 37 Fed. Reg. 2877 (Feb. 8, 1972), *as amended by* Executive Order No. 11,989, 42 Fed. Reg. 26,959 (May 24, 1977). The 2015 revised Travel Management Rule requires that the designation of areas and trails to be used by OSVs "*shall consider effects on the following, with the objective of minimizing:*

(1) Damage to soil, watershed, vegetation, and other forest resources;

(2) Harassment of wildlife and significant disruption of wildlife habitats;

(3) Conflicts between motor vehicle use and existing or proposed recreational uses of National Forest System lands or neighboring Federal lands; and

(4) Conflicts among different classes of motor vehicle uses of National Forest System lands or neighboring Federal lands." [3]

The OSV Rule is about far more than simply designating OSV use in places where OSV users would like to ride. The Forest Service must consider how OSV designations will impact other uses and forest resources and ensure that these impacts are minimized. This may mean restricting OSV use in areas where it is currently allowed, even in areas that are highly desired by OSV users. We appreciate that the purpose and need for this project, as outlined in the DEIS, includes promoting public safety and minimizing conflict and impacts. We worry, however, that the Forest Service is construing the purpose and need of this OSV designation process in such a way as to simplistically consider the issues at hand simply as "where do OSV users desire to recreate". In truth, the STF must consider non-motorized recreation uses, the preservation of wilderness character, wildlife, and natural resources on a level playing field with the desires of the OSV community.

MINIMIZATION

The minimization criteria are the heart of travel management planning. They require the Forest Service, when designating routes and areas open to motorized travel, to: 1) minimize damage to soil, watershed, vegetation, or other resources of the public lands; 2) minimize harassment of wildlife or significant disruption of wildlife habitats; and 3) minimize conflicts between off-road vehicle use and other existing or proposed recreational uses of the same or neighboring public lands. These minimization criteria were codified in the 2005 Travel Management Rule, as amended by the 2015 Over-Snow Vehicle Rule.

[2] 80 Fed. Reg. 4500, Jan. 28, 2015, 36 C.F.R. part 212, subpart C

[3] 36 CFR Section 212.55(b)

Forests must apply and implement the minimization criteria when *designating* each area and trail where OSV use is permitted,[4] not as a means of justifying existing management. Any areas where cross-country OSV use is permitted must be "discrete, specifically delineated space[s] that [are] smaller . . . than a Ranger District" and *located* to minimize resource damage and conflicts with other recreational uses.[5] The minimization criteria must come first, followed by drawing lines on the map.

Application of the criteria requires the Forest Service to minimize impacts — not just identify or consider them — when designating areas or trails for OSV use, and to demonstrate in the administrative record how it did so. This duty was recently confirmed by the Ninth Circuit Court of Appeals in *WildEarth Guardians v. U.S. Forest Service*[6] in which the Court held that the agency must "apply the minimization criteria to each area it designated for snowmobile use" and "provide a more granular minimization analysis to fulfill the objectives of Executive Order 11644, which the [Travel Management Rule] was designed to implement." More specifically, the Court held that "mere 'consideration' of the minimization criteria is not enough." The Forest Service must show not just that impacts have been studied, but specifically demonstrate how effective each of the Alternatives presented in the DEIS is in minimizing impacts from OSVs. As one of the first forests to implement the new OSV rule, it is critical that the STF properly apply the minimization criteria.

Table D-10 in the DEIS describes the minimization criteria screening exercise. This is a good start towards applying the minimization criteria, but it is difficult to determine what the different designation recommendation codes mean. As best we can tell, Alternatives 2, 3, and 5 incorporate some boundary adjustments aimed at minimization, but this is not explicitly spelled out in the DEIS. Likewise, the DEIS does not explain how or whether designated trails have been located to minimize impacts in each alternative. The DEIS does list many different mitigation measures, but mitigation is not a substitute for minimization. In addition, many of the mitigation measures listed rely on uncertain future monitoring, are unenforceable, and lack specificity and clear triggers for implementation. Additionally, it is unclear whether these mitigation measures would even be effective in reducing impacts. For these reasons, mitigation cannot be the first line of defense in minimizing OSV impacts. The OSV use system on the forest – designated routes and areas – must be *designed* to minimize impacts. Mitigation is a secondary measure.

Furthermore, the DEIS does not include a robust analysis of OSV impacts to at-risk wildlife on the STF and fails to offer alternatives that comply with the OSV rule's requirement for minimizing impacts to wildlife, including Pacific marten, fisher, Sierra Nevada red fox, Yosemite toad, and sooty grouse. Designating OSV use within Near Natural areas – areas that were previously deemed unsuitable for motorized use in order to protect forest carnivores – runs contrary to the Forest Service's obligation to minimize harassment of wildlife and significant disruption of their habitat by OSVs. See page 18 below for more details regarding the requirement to minimize harassment of wildlife and significant disruption of wildlife habitat.

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[4] 36 C.F.R. §§ 212.81(d), 212.55(b).
[5] 36 C.F.R. §§ 212.1, 212.81(d), 212.55(b).
[6] *WildEarth Guardians v. U.S. Forest Service*, 790 F.3d 920 (9th. Cir. 2015).

Minimize conflicts between motor vehicle use and existing or proposed recreational uses of Forest Service lands or neighboring Federal lands

Page 122 of volume 1 of the DEIS and pages 20-21 of volume 2 accurately describe the types of conflict that occur between motorized and non-motorized winter recreation. However, the DEIS fails to fully describe how or where these types of conflict are occurring on the STF, because it does not recognize or discuss the history of non-motorized recreation and use conflict on the STF or that certain areas on the STF are more valuable for non-motorized winter recreation than others. The DEIS does not fully explain that even safe, legal, operation of OSVs can bring substantial conflict with other recreational uses.

IMPORTANT HUMAN-POWERED WINTER RECREATION AREAS

Rather than utilize the extensive information that we and others provided at scoping detailing where skiers, snowshoers, and splitboarders recreate and where non-motorized recreationists are experiencing conflict on the STF, the DEIS relies on modeling (for example, Table 30 on page 109 of the DEIS) to predict where non-motorized winter recreation might occur and which areas may be valuable for non-motorized winter recreation. While this sort of modeling provides a useful high-level understanding of non-motorized winter recreation use on the forest, it is no substitute for the on-the-ground knowledge that scoping commenters provided and that the STF appears to have ignored. Likewise, while it is somewhat informative to understand how the Alternatives differ in regards to total acres of NFS lands not designated above 5,000 feet in elevation, within 5 miles of Sno-Parks, within 5 miles of ski resort parking areas, and along Highways 4, 207, and 108, and Dodge Ridge Road, or the percent change in such acres not designated between each alternative and the current condition, it would be <u>far</u> more informative if the EIS ran these comparisons for the specific highly desirable, historically utilized non-motorized areas that we and others described in our scoping comments. This would also be a more equitable way of conducting the analysis, considering the DEIS specifically examines changes to highly desirable, historically utilized OSV areas.

There are several specific areas within Stanislaus NF that are highly desirable for and historically utilized by skiers, snowshoers, and splitboarders. We described these areas in great detail in our August 2015 scoping comments. After considering the information presented in the DEIS, we have decided to modify slightly the boundaries of Big Meadow, Herring Creek, and Dodge Ridge non-motorized areas from what we proposed in 2015. These modified boundaries are depicted on the maps in Attachment 1. We are also submitting a GIS shapefile of these areas (Attachment 2) with these comments so that the Forest Service is able to more easily analyze these areas. Given that the DEIS never once mentions that there are areas on the STF that are historically used and highly desirable for non-motorized winter recreationists, we feel it is necessary and important to re-iterate our descriptions of these areas. We also encourage the STF to review our August 2015 comments.

While we appreciate that Alternative 3 largely reflects the Alternative we submitted in 2015, it is very concerning to us that the DEIS repeatedly emphasizes “highly desirable, historically available” OSV recreation areas without once mentioning that there are highly desirable, historically utilized non-motorized winter recreation areas on the STF, or that unmanaged OSV recreation has displaced non-motorized users from many of these highly desirable, historically utilized areas. We described these issues in extensive detail in our August 2015 comments. OSV recreation is not the only, or even the most popular, form of winter recreation on the STF, but one wouldn’t know that by reading this DEIS.

Two of the areas, Round Valley and Dodge Ridge are closed to snowmobiles in Alternative 5. The remaining five areas, which comprise about 1% of the forest, are designated for OSV use in Alternative 5. In order to minimize the conflict between motorized and non-motorized recreation, these areas should also not be designated for OSV use.

Round Valley

This area lies between Mt Reba and Highway 4 and is the most popular area near Bear Valley for backcountry skiing and snowshoeing. This area offers outstanding terrain for intermediate and advanced skiers and snowshoers. The area is easily accessible from the Round Valley Sno-Park. Currently, this is the only non-wilderness area within the Bear Valley region that is closed to snowmobiles and easily accessible from a plowed trailhead. We appreciate that it is not designated open to OSV use in any of the action alternatives. However, OSV trespass into this area is common. Some is directly from the Lake Alpine Sno-Park, where all lands to the north are off-limits to OSV use, but no signage has been present for many years. Signs are also needed along the southern boundary of Bee Gulch and Woodchuck Basin. Here, too, snowmobile trespass is common.

The popularity of this area with non-motorized users indicates the demand for non-motorized areas within the Bear Valley region along Highway 4. Four such areas that should be set aside for non-motorized winter recreation are described in the paragraphs, below.

Osborne Hill and Lake Alpine

This area is located just south of Highway 4 near Lake Alpine, within the proposed Alpine OSV use area. The area runs from the Lake Alpine Sno-Park on the west to a short distance past Lake Alpine to the east. While not heavily used by either skiers or snowmobilers, this area makes a good area for intermediate skiers seeking a short tour from the Lake Alpine Sno-Park or a longer challenging tour into the Carson-Iceberg Wilderness lying to the south.

The Osborne Hill ski tour is described in a 1985 backcountry skiing guidebook.[7]

This area is designated as open to OSV use in Alternative 5 but should be closed as in Alternative 3. We would support designating an OSV route to the south towards Spicer Reservoir on Forest Road 7N17 to give OSV access to the Spicer North and Spicer OSV areas desired by snowmobilers. This route, and others that we reference in these comments, is depicted in the GIS shapefile included with these comments as Attachment 3.

Big Meadow

This small area is located on the south side of Highway 4 near the Big Meadow campground, partially within the proposed Spicer OSV use area. The area provides excellent beginner terrain south of the highway for short, easy tours with scenic views of the North Fork Stanislaus River valley. Two tours in this area are described on the Backcountry Ski Tours website (http://www.backcountryskitours.com). Access is from the plowed-out entrance road to the campground, which normally has parking for a few cars but no easy snowmobile access.

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[7] *Ski Tours in the Sierra Nevada Volume 2*, M. Libkind, Bittersweet Publishing Co., 1985, pg. 103.

This area has historically been managed for non-motorized winter recreation. Much of the area lies within a near natural area and is not designated for OSV use in any of the alternatives. Alternative 3 does not designate additional land adjacent to the near natural area and around the campground. This additional area encompasses one mile of marked trail and approximately another mile of good terrain for beginner through beginner-intermediate skiers. Approximately 12% of this area is designated for OSV use in Alternative 5 - this does not adequately protect the non-motorized recreational values in the area or minimize conflict between non-motorized and motorized recreation uses. The final plan should not designate any of the Big Meadow area as mapped in Attachments 1 and 2.

Cabbage Patch to Black Spring

This area is north of Highway 4, within the proposed North Highway 4 OSV use area. It is accessed using FR 7N09 (Cabbage Patch Road). It is bounded by St Michele Meadow on the east, FR 7N09 on the north, FR 7N23 (Black Spring Road) on the west, and Highway 4 on the south.

This area affords good beginner to low-intermediate touring terrain utilizing the many unplowed roads in this area and the moderately-sloped ridge. Three ski tours in this area are described on the Backcountry Ski Tours website at http://www.backcountryskitours.com. The December 1999 Ebbetts Pass Area Winter Recreation Guide shows 35 miles of ungroomed trails in the area north of Highway 4 stretching from Cabbage Patch to Black Spring. These trails are open to both motorized and non-motorized recreation, but use is heavily skewed toward non-motorized use because there is no staging area for snowmobiles.

Over the last several years, on-the-ground experience shows that the Cabbage Patch to Black Spring area receives almost no OSV use. Furthermore, the Cabbage Patch to Black Spring area has the necessary terrain, roads, and mild ridges to support a major backcountry non-motorized trail system similar to that developed in the Foster Meadow area on Highway 88.[8]

This area is designated as open to OSV use in Alternative 5 but should not be designated in the final plan. We would support designating FR 7N09 (Cabbage Patch Road) as an OSV route to provide access through this area for snowmobiles to OSV areas farther to the north.

Mattley Ridge

This area is north of Highway 4, within the proposed North Highway 4 OSV use area. It is accessible via Forest Road 7N09 (Cabbage Patch Road) from its intersection with Highway 4 just west of the Cabbage Patch State Highway Maintenance station. Beginning skiers and snowshoers can travel into Thompson Meadow and Del Orto Camp utilizing unplowed roads. Intermediate skiers can continue up FR 7N09, turning off onto FR 7N72 and then continuing up Mattley Ridge from where FR 7N72 ends. From the top of Mattley Ridge, skiers can either turn around and ski down the open, intermediate slopes or continue on the ridge towards Flagpole Point and circumnavigate the bowl containing Thompson Meadow staying on a ridge top almost the entire way. The ridge loop tour may also be skied in the other direction (counterclockwise), ending with a ski down the open slopes on Mattley Ridge.

The Mattley Ridge area has historical significance for non-motorized users. Four tours in this area, plus the route along ridges from Bear Valley Ski Resort to Flagpole Point and then to Cabbage Patch, are

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[8] See http://www.backcountryskitours.com/pages/tours_1000/1008_tour.htm.

described in a 1985 backcountry skiing guidebook.[9] The description of the tour along the ridges begins with: “If there is a classic tour in the Bear Valley area it is the ski along the high ridges.” Today these ridges are inundated with OSV use, and non-motorized recreationists have been displaced by the heavy snowmobile use. Five miles of ridge connect Bloods Point near Bear Valley to Flagpole Point. If the Mattley Ridge area were not designated for OSV use, as in Alternative 3, it would reduce the amount of ridge terrain open to OSVs by one mile.

This area is designated as open to OSV use in Alternative 5 but should not be designated in the final plan without a seasonal restriction in order to alleviate use conflict and halt displacement of non-motorized visitors. We would support designating FR 7N09 (Cabbage Patch Road) as an OSV route season to provide access for OSVs to the residences in the St Michele Meadow area and to the OSV areas farther to the north and west.

This area could also be closed to OSV use on a conditional basis depending upon the status of Highway 4. Under this plan, the Mattley Ridge area would be closed when the season begins, but would be designated as open when OSV access to Highway 4 starting at the Lake Alpine Sno-Park is unavailable due to the plowing of the highway. This concept is described below in the section “**Conditional OSV Designation**” on page 9.

Dodge Ridge

There are two areas on either side of the Dodge Ridge Wintersports Area near Pinecrest on Highway 108. These areas are the location of marked backcountry ski and snowshoe trails. The area is patrolled in the winter by the Pinecrest Nordic Ski Patrol and is the most popular area for backcountry skiing and snowshoeing along Highway 108. There is parking at either of two trailheads: Crabtree on the south side of the downhill ski area and Gooseberry on the north.

Nine tours in this area are described in a 1985 backcountry skiing guidebook.[10]

This area is not designated for OSV use in either Alternative 3 or 5, but is in Alternative 4 (within the proposed Highway 108 West OSV area). This area should not be designated for OSV use in the final plan.

Herring Creek

The junction of Herring Creek Road and Highway 108 and the junction of Forest Road 5N40Y and Highway 108 at Cow Creek are the only two other trailheads of value for non-motorized winter recreation along Highway 108. The snow-covered roads that emanate from these trailheads crisscross the lands to the east of Highway 108, and it is possible to reach all points to the east from either trailhead. There are 25 miles of ungroomed roads in this area currently available for OSV use. 23 of these miles are also designated for ATV use, which rut the snow such that they are impassable by non-motorized winter recreationists and difficult for OSVs to traverse as well. We would like to see a small portion of this area not open to OSV use in the winter.

The area of value for non-motorized recreation is located south of Highway 108 north of Pinecrest Lake, within the proposed Highway 108 OSV use area. This area is not designated for OSV use in Alternative 3.

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[9] *Ski Tours in the Sierra Nevada Volume 2*, M. Libkind, Bittersweet Publishing Co., 1985, pp. 88-100.
[10] *Ski Tours in the Sierra Nevada Volume 2*, M. Libkind, Bittersweet Publishing Co., 1985, pg. 109-121.

This would reduce the mileage of ungroomed road available for OSVs from 25 miles to 20 miles, but maintain access for snowmobiles to Bull Run, the Punch Bowl, and the loop around Hammill Canyon. Five miles of Herring Creek Road (Forest Road 4N12) from Highway 108 to its intersection with Forest Road 5N17, and lands north and adjacent to the road should be non-motorized in winter to provide a non-motorized loop for skiers and snowshoers.

Herring Creek Road provides access to snow play areas and also beginner level tours into the Punch Bowl area. This area is the best location for creating an additional non-motorized opportunity area for skiing, snowshoeing, and family snow play along Highway 108 to supplement the areas at Dodge Ridge as described above.

Three tours in this area are described in a 1985 backcountry skiing guidebook.[11]

The Herring Creek area could be closed for OSV use during the winter season but open for OSV use when plowing of Highway 108 ends access beyond the Highway 108 Sno-Park. This conditional designation is described in the section "Conditional OSV Designation" on page 9, below.

Recommendations

- Do not designate for OSV use the important non-motorized areas described above: Round Valley, Osborne Hill/Lake Alpine, Cabbage Patch to Black Spring, Big Meadow, Dodge Ridge
- Designate OSV use with a restricted season, as described in the Conditional OSV Designation section below, for Matttley Ridge and Herring Creek.

CONDITIONAL OSV DESIGNATION

The concept of conditional OSV designation is a way to separate conflicting uses of the forest for most of the winter season, but also permit the sharing of the diminishing snowpack resource in the spring. At that time, much of the forest normally open to OSV use becomes inaccessible due to the plowing of highways, which can begin when there is still adequate snow on the ground for recreation. At that time, areas normally set aside for non-motorized recreation could be opened to motorized use. This adaptive management strategy would be more flexible than using fixed dates to determine when areas should become shared-use.

There are two areas on the STF that are important for human-powered winter recreation but could be designated for OSV use in the spring. These areas are Mattley Ridge and Herring Creek, both of which we described in the previous section of these comments. When Highways 108 and 4 are plowed OSV users are unable to visit the remote areas normally accessible from the Lake Alpine and Highway 108 Sno-Parks. To compensate for this and to allow late-season OSV access to STF lands, the STF could allow OSV use in Herring Creek and Mattley Ridge areas once their respective highways begin to be plowed.

This management plan would allow both non-motorized and motorized over-snow recreation in these areas, with use conflict minimized through a seasonal separation of uses. Skiers and snowshoers would have access to both Mattley Ridge and Herring Creek for quiet recreation for much of the winter. As we have previously described, these areas both have a long history of non-motorized use and are highly

[11] *Ibid*, pp. 122-126.

valued by backcountry skiers and snowshoers. However, we believe it is reasonable to allow late-season use in both Herring Creek and Mattley Ridge. This seasonal restriction would allow both non-motorized and motorized over-snow recreation to enjoy these areas, with use conflict minimized through a seasonal separation.

Recommendation

- If designated, only allow OSV use in the Mattley Ridge and Herring Creek areas once plowing begins on Highways 4 or 108, respectively.

PACIFIC CREST TRAIL

Considering that almost the entirety of the Pacific Crest Trail (PCT) on the STF lies within designated Wilderness, recommended wilderness, or a near natural area, the only place where the STF should even consider designating OSV use along the trail is where the trail crosses Highway 108. In areas where the trail is located on the Toiyabe National Forest but within 500 feet of the STF, the Forest Service should not designate areas for OSV use within the Scenery Management System definition of Foreground for the trail. Doing otherwise will bring high potential for conflict between motorized and non-motorized uses on and along the PCT and conflict with the Forest Service's mandate to manage the PCT as a Congressionally-designated national non-motorized trail.

Snowmobiling along – not simply *on*, the trail is specifically called out as a management concern in the Comprehensive Plan[12] and listed among the reasons that a Comprehensive Plan was necessary. Page 21 of the PCT Comprehensive Plan states that: "*Snowmobiling along the trail is prohibited by the National Trails System Act, P.L 90-543, Section 7(c). Winter sports plans for areas through which the trail passes should consider this prohibition in determining areas appropriate for snowmobile use*." This language, particularly the reference to "*areas through which the trail passes,*" make it clear that areas around the PCT must be managed in a way that protects the non-motorized character of the trail. As further evidence that the Comprehensive Plan intends for areas adjacent to the trail—not merely the tread of the trail itself—to be managed as non-motorized, the Comprehensive Plan also states: "*If cross-country skiing and/or snowshoeing is planned for the trail, any motorized use of adjacent land should be zoned to mitigate the noise of conflict*."[13]

The STF's final winter travel plan must be forward-looking. Although winter use on the trail may currently be relatively limited, long-distance backcountry ski touring is on the rise worldwide, and winter use on the trail is highly likely to increase significantly over the life of the travel plan.

In addition to complying with the PCT Comprehensive Plan, we see no practical reason to designate areas for OSV use within close proximity to the PCT. OSVs are not allowed to cross the PCT unless the STF designates specific crossing points. There is little to be gained for OSV users if they are allowed to ride within the area directly adjacent to the PCT, but allowing this use invites the temptation for OSV users to cross the trail at points outside of the designated routes. In addition, while there is nothing to be gained in this scenario, it will be extremely frustrating for OSV users if they're allowed to ride right up

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[12] Pacific Crest Trail Comprehensive Plan at pages 13 and 15, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5311111.pdf
[13] Pacific Crest Trail Comprehensive Plan at page 21

to the trail on either side but not cross it. In reality, the non-motorized status of the trail will be ignored. Designating OSV use areas directly adjacent to the PCT, regardless of how far the particular section of trail is from a plowed road, or how many people are visiting the trail or area in the winter, is a recipe for non-compliance and failure of the travel plan.

Finally, we want to bring attention to, and raise issue with, a statement that is repeated several times in the DEIS: “Access to the PCT on the Stanislaus National Forest is very limited in the winter due to the distance of the trail from plowed roads and parking areas (two segments outside of Wilderness are 15 and 26 miles from plowed roads and parking). The only access to the Stanislaus National Forest segments of the PCT in the winter would be by OSV.” This statement reflects a lack of understanding both about human-powered winter recreation and PCT travel. Just as many hikers enjoy backpacking, there is a significant sector of the backcountry/cross-country ski and snowshoe community who enjoy winter camping and multi-day trips. People travel all or portions of the PCT in winter, including on multi-day trips. And, in certain conditions (supportable crust), traveling over 30 miles in a day on foot, on skis, is not an unreasonable feat. Especially in the spring along the Sierra Crest, where the PCT is located, cross-country skiers enjoy “crust cruising” – essentially skate skiing but with no need of a groomed trail – and can cover dozens of miles in just a few hours.[14] There is no basis for the Forest Service’s claim that the only way to access the PCT in winter, presumably once one is more than 5 miles from a plowed road, is by OSV.

Recommendations:

- Designate Highway 108 as a PCT crossing point. Do not designate other areas adjacent to the PCT for OSV use.

NEAR NATURAL AREAS

Each of the Alternatives in the DEIS, except Alternative 3, propose to designate OSV within designated near natural areas. This would require a forest plan amendment, as the Stanislaus forest plan unequivocally states that near natural areas are not suitable for motorized use and that they should be managed as semi-primitive non-motorized.[15] Forest plan direction is that near natural areas, including Eagle/Night and Pacific Valley, are closed to motorized use. It is unfortunate that the STF has not enforced this forest plan direction for decades, but that does not alter the fact that these areas were designated near natural and were supposed to be closed to motorized use for a reason. Eagle/Night and Pacific Valley both contain important habitat for rare forest carnivores (Sierra Nevada red fox and Pacific marten), are popular with non-motorized winter recreation visitors, and have high potential for future Wilderness recommendation in the upcoming forest planning process. Just because the STF has allowed unauthorized OSV use to proliferate by turning a blind eye in the past is insufficient justification to overrule all of the reasons that these areas were designated near natural in 1991. If the STF no longer feels these areas are deserving of a near natural designation that is a decision that must be made in

[14] See for example: https://fasterskier.com/fsarticle/sierra-backcountry-skating/

[15] STF Forest Plan Direction. 2017. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd535378.pdf Stating, as an example, on page 115: “Emphasis is placed on providing a natural appearing landscape in a non-motorized setting. Public motorized use is not normally allowed, and no timber harvest is scheduled.” And “It meets the Forest Service criteria for the Recreation Opportunity Spectrum class of Semi-primitive Nonmotorized.”

forest planning when the Forest Service takes a more holistic look at the desired future for these areas and the appropriate management to achieve that future.

Travel planning does not drive forest planning, but, rather, must comply with the forest plan. We recognize that this can put the Forest Service in a difficult position if they have not fully enforced their forest plan in the past. We recently witnessed a similar situation on the Bitterroot National Forest, where the forest plan dates back to the 1980's but the travel plan was just completed in 2016. As part of the travel planning process the Forest Service concluded that, to maintain and manage for wilderness character, OSV use would no longer be permitted in recommended wilderness areas. Similar to the STF, OSV use had proliferated across the Bitterroot in the absence of any management decision-making by the Forest Service. However, the Forest Service recognized that the travel plan needed to comply with the Forest Plan and made the politically difficult decision to prohibit OSV use in recommended wilderness areas and wilderness study areas where it had long been established. Snowmobile groups challenged the travel plan decision, but it was recently upheld by the Montana district court.[16]

Not only is travel planning not an appropriate time to make forest plan amendments of this magnitude, especially considering that the STF is on pace to begin forest plan revision shortly, amending the forest plan is far more complicated than the DEIS belies. If the STF were to proceed with a forest plan amendment, the amendment is subject to the 2012 planning rule provisions at 36 C.F.R. part 219, and not the provisions of the 1982 planning rule under which the current forest plan was developed.[17] In addition, the amendment would need to comply with the amendment provision of the 2012 planning rule, which outlines how to amend forest plans written under the 1982 rule.[18] The proposed plan amendments in Alternative 4 would be directly related to the substantive requirements within §§ 219.8 through 219.11 of the 2012 Rule, and therefore the Forest Service must ensure that the amendment satisfies these requirements. These requirements include providing for ecological sustainability by "maintain[ing] or restor[ing]": (a) "the ecological integrity of terrestrial and aquatic ecosystems and watersheds," including "structure, function, composition, and connectivity;" (b) air and water quality, soils and soil productivity, and water resources; and (c) "the ecological integrity of riparian areas," including their "structure, function, composition, and connectivity."[19] Plans must also provide for: (a) "the diversity of plant and animal communities;" (b) "the persistence of native species;" and (c) "the diversity of ecosystems and habitat types."[20] In providing for social and economic sustainability, plans must account for "[s]ustainable recreation; including recreation settings, opportunities, and access; and scenic character."[21] The decision document for the plan amendment "must include . . . [a]n explanation of how the plan components meet [those substantive] requirements."[22]

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[16] *Bitterroot Ridge Runners Snowmobile Club vs. United States Forest Service.* Case 9:16-cv-00158-DLC, Filed 06/29/18

[17] 36 C.F.R. § 219.17(b)(2) (following a 3-year transition period that expired May 9, 2015, "all plan amendments must be initiated, completed and approved under the requirements of this part").

[18] 36 C.F.R. § 219, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd527654.pdf

[19] 36 C.F.R. § 219.8(a).

[20] 36 C.F.R. § 219.9.

[21] 36 C.F.R. § 219.8(b)(2).

[22] 36 C.F.R. § 219.14(a)(2).

In addition to its substantive provisions, the 2012 planning rule prescribes the process for a plan amendment. The process for amending a plan includes: Preliminary identification of the need to change the plan, development of a proposed amendment, consideration of the environmental effects of the proposal, providing an opportunity to comment on the proposed amendment, providing an opportunity to object before the proposal is approved, and, finally, approval of the plan amendment. The appropriate NEPA documentation for an amendment may be an environmental impact statement, an environmental assessment, or a categorical exclusion, depending upon the scope and scale of the amendment and its likely effects.[23] All of these 2012 planning rule prescriptions would need to be complied with if the STF were to revise the forest plan to accommodate OSV use in near natural areas.

Both the Pacific Valley and Eagle/Night Near Natural Areas are prime candidates for wilderness recommendation and are currently closed to motorized use under the existing forest plan. They should not be designated for OSV use unless and until the Forest Service determines through a full forest plan revision that winter motorized use in these areas is warranted and consistent with all relevant legal obligations. At that time (during forest plan revision), amendments to the winter travel plan and OSVUM could be proposed and considered. Although Alternative 5 only designates portions of both the Pacific Valley and Eagle/Night Near Natural Areas for OSV use, these designations would erode the Near Natural values across the entirety of both areas and conflict with current forest plan direction (not just the semi-primitive non-motorized ROS but also direction to protect their exceptional wildlife habitat, ecological, and primitive recreation values). Alternative 5 would allow two long fingers of OSV use areas to extend far into the heart of the Pacific Valley Near Natural Area, essentially eliminating that area from future wilderness consideration by allowing extensive motorized use into its wild heart. It would also allow the entire western half of the Eagle Near Natural Area to be open to OSV use, all the way to the Emigrant Wilderness boundary. Like Pacific Valley, designating so much of the Eagle area for OSV use will severely limit the possibility of adding this highly desirable wild area to the Emigrant Wilderness in the future. OSV planning should not foreclose on future opportunities for wilderness recommendation, especially when forest plan revision is just around the corner.

Finally, Alternative 5 would allow OSV use to occur far up into Long Valley. It is likely this designation will inadvertently allow for OSV use up the steep open slopes on both sides of the designated area, within the eastern portion of the Eagle Near Natural area. Alternative 5 would also open a portion of the Night Near Natural Area adjacent to Highway 108 at the very top of the Sonora Pass on the south side of the highway. Similar to the problem of containing snowmobiles within the area in Long Valley proposed for OSV use, this new open area at the top of the Sonora Pass would also be very difficult if not impossible to enforce to keep trespass out of the rest of the Near Natural Area and out of adjacent wilderness.

MINIMIZE DAMAGE TO SOIL, WATERSHED, VEGETATION AND OTHER FOREST RESOURCES

The National Core Best Management Practices (BMPs) for OSV use in Forest Service Manual 7716 instruct the Forest Service to designate a minimum snow depth and OSV season dates, and to manage by class of vehicle in order to protect underlying vegetation and soil. We are pleased to read in the DEIS that the STF intends to continue utilizing snow depth as a management tool, and we ask that the STF

[23] 36 C.F.R. § 219.5(a)(2)(ii); *see also id.* § 219.13(b)(1) (explaining that "[t]he responsible official shall . . . [b]ase an amendment on a preliminary identification of the need to change the plan").

consider how season dates and managing by class of vehicle[24] could be utilized to further comply with these BMPs as part of the overall goal of minimizing impacts to forest resources. Recent research examining early season snowpack loss in the Sierra Nevada, and implications that these changes have for OSV travel planning indicates that the onset of the over-snow recreation season in the Sierra has shifted by approximately 2 weeks.[25]

The Sierra Nevada is already seeing the effects of a changing climate, particularly in relation to the snow season. In a recent study, scientists identified an alarming and statistically significant decline in winter snow levels in the northern Sierra Nevada over the past 10 years.[26] Over this time period, the winter snowline in the northern Sierra Nevada has risen by approximately 1,200 feet. This trend is expected to continue into the future. Due to these impacts, land managers and recreationists cannot assume that areas that supported winter recreation in the past will continue to do so into the future. These findings support the STF's proposals to only designate areas above 5,000 feet in elevation for OSV use. It makes sense that in winter travel planning the STF would only designate areas for OSV use that receive consistent and ample snow throughout the winter. The STF should not designate areas that rarely receive sufficient snow for OSV travel (including the Interface Area), as these areas likely won't continue receiving snow into the future. Low elevation areas provide, at best, low quality OSV riding opportunities and generally don't receive enough snow to support OSV riding at all. However, they do contain other values like habitat for species including the California red-legged frog, mule deer, and bald eagles. Considering that climate change is causing the STF's snowline to move higher, designating low elevation areas for OSV use does not comply with the OSV Rule's requirement to conduct winter travel planning in areas that receive sufficient snow to support over-snow recreation. We fully support not designating low-elevation areas for OSV use.

Defining a minimum snow depth for OSV use is also an important tool for managing winter recreation in the era of a rapidly changing climate. Minimum snow depths help management be flexible and responsive to changing snowpack. The STF should set seasonal bookends that define the OSV use season beyond what the forest has proposed in Alternative 5 for Sonora Pass. Season dates can help minimize conflicts between uses (as proposed in the previous section), help to minimize impacts on wildlife (for instance, implementing a limited operating period during a sensitive species breeding period), and minimize impacts to resources (for example, eliminating use when vegetation is producing new growth or soils are beginning to thaw). There are other adaptive management approaches that the STF could consider incorporating into this plan to address changes in early-season snowpack. Adaptive management tools should be considered as tools that the STF may incorporate later, if monitoring indicates they are necessary. Although some of these tools may not be (and, unless necessary, should not necessarily be) utilized initially, if STF OSV plan includes monitoring questions, clear triggers, and

[24] For example, the Tahoe National Forests has proposed differentiating between 2 classes of OSVs based on vehicle size, and only permitting larger tracked vehicles on groomed routes rather than also allowing them to travel cross-country.

[25] Hatchett, B. J. and Eisen, H. G.: Brief Communication: Early season snowpack loss and implications for over-snow vehicle recreation travel planning, The Cryosphere Discuss., https://doi.org/10.5194/tc-2018-181, in review, 2018.

26 Hatchett et al. 2017. Winter Snow Level Rise in the Northern Sierra Nevada from 2008 to 2017. *Water*: *9*(11), 899; https://doi.org/10.3390/w9110899. Included as Attachment 4.

management responses the STF may be able to adapt management to continue to support a winter recreation program even as snow seasons change. Some adaptive management ideas are presented in in the following table from Hatchett and Eisen 2018[27]:

Adaptation Measure	Benefit(s)	Challenge(s)
Requirement of minimum snow depth off trail, but not on roads, or a lower minimum snow depth on roads	Allow OSV use even under extremely low snow conditions; grooming could be utilized to maximize snow depth on road	Preventing users from going off trail under low snow conditions; enforcement
Ensure high elevation access via a right-of-way	During warmer/drier years, snow conditions are likely to be better (deeper snowpack) at higher elevation	User group conflicts; presence of Wilderness at high elevation; impacts to snow-dependent wildlife species; demand; parking
Removal of blanket opening dates	Prevents opening before SWE_{min} achieved and will limit damage to landscape	Resources required to obtain snow condition information
Identify corridors that collect/retain more snow	During otherwise poor snow conditions, these areas may allow OSV recreation to occur, particularly at lower elevation areas	Need for data on these corridors
Trade-off: closure of low elevation/sensitive habitat for improved high elevation access	Eliminate chance of damaging landscapes in low elevation regions, increase in the number of days/year that OSV recreation can occur by enhanced high elevation access	Need for collaboration between stakeholders/user groups to identify areas where compromise could occur. May be opposed by those who must travel much further for OSV use.
Fee increases to enhance access and offset impacts from higher demand (i.e., restoration projects)	Would provide for additional resources to monitor trailhead conditions, improve parking/bathrooms at trailheads, fund restoration projects and creation of low-snow OSV trails	Fees are generally opposed by members of the public.

SNOW DEPTH

We are pleased to see that each action alternative in the DEIS includes at least a 12 minimum snow depth for all OSV use on the forest. The DEIS makes a strong argument for requiring a minimum snow depth of at least 12 inches across the forest. For example, on page 18 the DEIS states "forest resource specialists, unanimously agreed that designating a minimum snow depth requirement in order to allow OSV use to occur was mutually beneficial and provided a means in which to minimize the likelihood of resource damage occurring as a result of OSV use." The DEIS also goes into great detail describing the many impacts that OSVs may have on forest resources without sufficient snowpack to protect these resources. In addition, the DEIS is clear in explaining that less than 12 inches of snow, and less than 24 inches in both Stanislaus Meadow and Highland Lakes would be insufficient for resource protection. For these reasons, we support the minimum snow depths proposed in Alternative 5.

There are a number of ways in which the STF can measure and enforce minimum snow depths, and we were pleased to see that the STF described it's intended management and enforcement approach on page 43 of the DEIS. As winter backcountry recreationists, we are aware that there is never a uniform level of snow across the landscape and that some areas can have extremely deep snow while nearby

[27] Table 1: Adaptation strategies to address loss of early winter snowpack for OSV recreation. from Attachment 5 - Hatchett, B. J. and Eisen, H. G.: Brief Communication: Early season snowpack loss and implications for over-snow vehicle recreation travel planning, The Cryosphere Discuss., https://doi.org/10.5194/tc-2018-181.

wind-swept ridges or south-facing hillsides may have none. This is the first time we have seen a forest in Region 5 actually describe how it intends to monitor and enforce minimum snow depth, including accounting for variations in snow depth, and we are pleased to see a viable plan presented. We do suggest, however, that the STF also consider how it will determine, and announce, when OSV trailheads are open for use (when minimum snow depth has been achieved).

We understand that the STF (and other forests) has limited staff capacity for snow depth monitoring. For that reason, we are working with Dr. Ben Hatchett, a snow scientist at the Desert Research Institute, to develop a predictive model relating SNOTEL and SNODAS data to snow depth at OSV trailheads in the northern and central Sierra Nevada.[28] Although the model is still under development, several findings from the preliminary study are applicable for STF OSV planning right now. One, it may be more useful for the STF to consider minimum snow density (measured as SWE). Two, snow depth and density can change dramatically throughout the snow season, and it is important that land managers be responsive to these changes in order to guard against resource damage. And, three, it is possible to utilize existing snow measurement stations to determine when there is sufficient snow on the landscape to open specific OSV trailheads.

Finally, we would like to alert the STF to ongoing research examining the issue of minimum snow depth. To our knowledge there has not been any quantitative research confirming a precise minimum snow depth necessary to protect against resource damage for Sierra Nevada snow conditions. However, we are also working with Dr. Hatchett at the Desert Research Institute to answer this question as well. Unpublished data from this ongoing research indicates that at least 18 inches of uncompacted snow is needed to protect against soil compaction. For this reason, we suggest the STF consider increasing the minimum snow depth to 18 inches in areas with sensitive soils.

SEASON DATES

To further comply with the requirement to minimize damage to forest resources, we urge the STF to expand the usage of OSV season dates beyond what is proposed in Alternative 5. Season dates should be considered bookends to the over-snow season, with minimum snow depth dictating more precisely when OSV use is allowed. Season dates help to protect forest resources in the shoulder season – both in the fall when people are eager to start their winter sports and in the spring when they are stretching the winter season to its very end. In both cases it is well documented that people – OSV users and skiers alike – are willing to travel over bare ground or ignore very low snow levels in order to reach areas with deeper snow. While skiers have the same impact as a hiker in this scenario, OSVs traveling over bare ground or minimal snow have the same impact as any other vehicle. These impacts include soil compaction, erosion, and vegetation damage. Season dates also help to separate uses to minimize conflict and minimize harassment of wildlife during the breeding season or other sensitive time periods.

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[28] Hatchett, Benjamin. 2017. Evaluation of Observed and Simulated Snow Depths for Commencing Over Snow Vehicle Operation in the Sierra Nevada. Report prepared for Winter Wildlands Alliance. Included as Attachment 6. And Hatchett, B. J. and Eisen, H. G.: Brief Communication: Early season snowpack loss and implications for over-snow vehicle recreation travel planning, The Cryosphere Discuss., https://doi.org/10.5194/tc-2018-181, in review, 2018.

As we discussed earlier in these comments, the snow season in the Sierra Nevada is changing significantly. On average, snow accumulation at OSV trailheads is now significantly later than was common 15 years ago.[29] In considering an appropriate season-opening date, the STF should consider historic "opening dates" based on snow accumulation as described in the research cited here. We suggest December 1 as an average opening date for the forest, but this may need to be adjusted depending on the elevation of various OSV trailheads.

As described on page 163 and elsewhere in the DEIS, the STF uses April 30 as the assumed end to the OSV season for the purposes of wildlife impact analyses. Given the reasons stated in the DEIS[30] we suggest that the STF winter travel plan set April 30 as the end of the OSV season across most of the forest and prohibit OSV use on the forest between May 1 and November 30. Considering OSV use drops off dramatically after March 31, an April 30 end-date is quite liberal and accommodates those who desire off-trail spring riding opportunities.

The final plan should also include more restrictive season dates for certain areas of the forest. For example, the STF could minimize conflict between uses in the Cabbage Patch to Black Spring and Herring Creek areas if it were to only authorize OSV use in these areas in the spring. Additionally, the Forest Service should apply a limited operating period for OSV use in Sierra Nevada red fox denning habitat to protect this rare species during a particularly vulnerable time of the year. The OSV season that the STF has proposed in Alternative 5 is wholly inadequate and contradicts recommendations by submitted to the STF during scoping by Sierra Nevada red fox (SNRF) experts. The forest plan requires limited operating period for SNRF from January through June to protect potential breeding. Because the most sensitive SNRF habitat proposed for designation is along Highway 108 starting at the Kennedy Gate, OSV use should only be allowed in this area prior to January 1. This and other wildlife-related minimization measures are described in the next section of these comments.

Given that climate change is altering snow seasons in the Sierra Nevada, including on the STF, the Forest Service should consider a variety of adaptive management strategies as part of this travel plan in order to further minimize impacts to soils, vegetation, and other natural resources. Several potential adaptive management tools are noted in Hatchett and Eisen 2018.

Recommendations:

- Do not designate low elevation areas (below 5,000 feet, and the Interface Area) for OSV use.
- Mandate a minimum snow depth of 12 inches for OSV travel on the forest, with greater depth restrictions in Stanislaus Meadow and Highland Lakes (24 inches), and in areas with soils that are particularly prone to compaction (18 inches).
- Set an OSV use season of December 1 – April 30 for most areas of the forest and in sensitive wildlife areas.

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[29] *Id*

[30] DEIS pg. 164: "Based on surveys of Forest Snow Parks and designated OSV route access points, OSV use was documented until the end of April, at which point snow levels no longer allow continued use of designated OSV routes (California Department of Parks and Recreation 2010). Therefore, for the purpose of this analysis, April 30 is used as a cut-off date for the maximum period of interaction between snowmobiles and wildlife."

- Incorporate adaptive management into the travel plan so that the plan is flexible and responsive to "abnormal" winters and snow conditions.

MINIMIZE HARASSMENT OF WILDLIFE AND SIGNIFICANT DISRUPTION OF WILDLIFE HABITATS

We incorporate by reference here comments submitted by Darça Morgan on behalf of our organizations. Among the concerns addressed in Ms. Morgan's letter, we wish to highlight that the DEIS does not include a robust analysis of project impacts to at-risk wildlife on the STF, and it has not yet proposed a responsible approach to managing for viable populations of at-risk wildlife. At-risk wildlife species include Pacific marten, fisher, Sierra Nevada red fox, Yosemite toad, and sooty grouse. The DEIS also fails to offer alternatives that comply with the OSV rule's requirement for minimizing impacts to wildlife. For example, designating OSV use within Near Natural areas – areas that were previously not deemed suitable for motorized use in order to protect forest carnivores – runs contrary to the Forest Service's obligation to minimize harassment of wildlife and significant disruption of their habitat by OSVs. Alternative 3 is the only alternative that minimizes impacts to wildlife, as it is the only alternative that does not propose to designate OSV use within areas that the Forest Plan determined should be non-motorized for the purposes of wildlife conservation.

ALTERNATIVES

The DEIS analyzes five alternatives. The Preferred Alternative, Alternative 5, does not fully comply with the minimization criteria of the Travel Rule, as it would designate important non-motorized recreation areas and sensitive ecological areas for OSV use. Alternative 3 does much more than Alternative 5 to minimize the conflict between motor vehicle use and other uses, and protects all important ecological areas on the forest, while still maintaining a robust OSV recreation program. Alternative 4 does not account for any other uses on the landscape, prioritizing OSV recreation above all other recreation and management uses and wildlife. Alternative 1, the Proposed Action, was first described in the scoping period in June, 2015. It would designate several important non-motorized recreation areas and two near-natural areas for OSV use and, like Alternative 5, does not minimize impacts to quiet recreation uses, wildlife, or natural resources. Alternative 2 does not meet the purpose and need of the project and reflects a status-quo in which the Forest Service has essentially *not* managed OSVs, allowing use to proliferate with no guidance.

As written, Alternative 3 is the only Alternative in the DEIS that complies with the Over-Snow Vehicle Rule. However, there are many positive elements in Alternative 5 and with some changes, incorporated from Alternative 3, a modified Alternative 5 could be a viable selected alternative.

Our thoughts on each of the alternatives are shared in more detail below.

Alternative 1

This alternative is the Proposed Action alternative and was first described in the scoping period in June, 2015. The alternative would designate 140,895 acres (15.7% of the forest) to OSV use, including the Pacific Valley and a portion of the Eagle/Night near natural areas, and all or part of five highly desirable, historically utilized non-motorized recreation areas. The important non-motorized recreation areas that would be designated in this Alternative are: Cabbage Patch to Black Spring, Mattley Ridge, Osborne Hill and Lake Alpine, a portion of Big Meadow, and Herring Creek. In addition, Alternative 1 would designate 24,767 acres and 44.68 miles of trail for OSV use in places that have previously received low to no OSV use. It also designates OSV use in populated areas where OSV use is not generally accepted, namely the Interface area, the Highway 108 West OSV area surrounding the Pinecrest/Dodge Ridge Designated Recreation Area, and the area surrounding the Experimental Forest.

Alternative 1 fails to minimize conflict between recreational uses in the four important non-motorized recreation areas listed above, as designating any portion of these areas for OSV use will do nothing to address the conflicts that currently exist in these areas, nor will it help stop displacement of non-motorized winter recreationists from desirable terrain across the STF. In addition, this alternative designates areas that provide little to no OSV opportunity and in places where OSV use would cause conflicts with people living nearby. It is not a thoughtful consideration of how best to designate OSV use on the STF, and we are pleased to see that the STF has developed additional alternatives to consider in this DEIS.

Alternative 2

This is the No-Action alternative that would maintain the current management of OSV use on the forest. This alternative does not meet the purpose and need of the project because it would not designate any areas or routes for OSV use and would continue the current approach of essentially not managing OSVs on the STF. This alternative does not comply with the Over-Snow Vehicle Rule or the Purpose and Need of this project and cannot be adopted.

In addition to not complying with the OSV Rule and Purpose and Need for the project, this Alternative as mapped and described paints an inaccurate and misleading picture of current OSV use on the STF. The maps and descriptions of Alternative 2 in the DEIS leave the reader with the impression that OSV use is currently feasible and occurring across 684,505 acres on the STF – every acre of the STF that is outside of designated Wilderness. This is inaccurate for several reasons. For one, much of the STF is either inaccessible (due to terrain or vegetation) for OSV use or does not receive enough snow, if any, to operate an OSV (generally, lands below 5,000 feet). Also, Forest Plan direction states that motorized use, including OSV use is not suitable in recommended wilderness, near-natural areas, special interest areas, or research natural areas. Therefore, the STF should never have allowed OSV use to occur in these areas. Where OSV use does occur within these designated areas it is not in compliance with forest plan direction.

In order to provide a useful and accurate baseline in this analysis, Alternative 2 should *accurately* reflect the current condition – it should depict where OSV use *actually* occurs on the STF and note where current usage is not in compliance with forest plan direction. In the FEIS the STF should revise its descriptions of Alternative 2.

Alternative 3

This alternative is based on the proposed alternative submitted by Snowlands Network and Winter Wildlands Alliance during the scoping phase. The alternative would designate as open 116,868 acres or 13.0% of the forest for OSV use and would not designate as open for OSV use about 18,000 acres or 2.0% of the forest where significant non-motorized recreation activity is currently taking place. That is, it would not designate any of the areas that we have described as highly desirable for non-motorized winter recreationists. Also, this alternative would not designate any Near Natural or Proposed Wilderness areas for OSV use. Thus, this alternative would fully comply with all of the minimization criteria of the Travel Rule and would be consistent with the existing Forest Plan.

As written, this alternative would designate portions of the Emigrant Road and Sonora-Mono Toll Road special interest areas for OSV use, encompassing 7.4 acres in total. These areas should not be designated for OSV use, and Alternative 3 should be modified accordingly. Likewise, at Big Meadow Campground on Highway 4, no portion of 7N02 above the 6400-foot level should be designated for OSV use.

Alternative 4

This alternative was submitted by motorized advocates during the scoping phase. The alternative would designate 191,099 acres (21.2%) open for OSV use, including 34,556 acres of Near Natural areas and 3,374 acres within Proposed Wilderness areas. This alternative, like Alternative 5, would designate OSV use in several of the areas where non-motorized recreation is taking place. Specifically, it would designate all or portions of Dodge Ridge, Herring Creek, Cabbage Patch to Black Spring, Big Meadow, Mattley Ridge, and the Osborne Hill and Lake Alpine backcountry ski and snowshoe areas. This alternative is also not consistent with the current Forest Plan as it would designate OSV use in areas where the Forest Plan states that OSV use is not suitable. It would also designate at least 24,767 acres and 44.68 miles of trail where there is little to no current or historic OSV use and no demand for OSV usage.

Alternative 4 would not minimize conflict between OSV use and other recreational uses, nor would it minimize impacts to and harassment of wildlife and their habitat. It does not offer any level of compromise or consideration for other uses and management goals. For these reasons, Alternative 4 is unacceptable.

Alternative 5

Alternative 5, the Preferred Alternative, would designate 97,963 acres (10.9%) open to OSV use, even less than Alternative 3. However, Alternative 5 would designate as open 6,053 acres within existing Near Natural areas and 382.3 acres within Special Interest areas. Alternative 5 would also designate as open for OSV use several areas where significant non-motorized recreation is occurring. Our specific concerns with Alternative 5 regarding quiet recreation are that it:

- Designates all of Mattley Ridge and Cabbage Patch to Black Spring as part of the North Highway 4 OSV area. This is a serious concern for us because these are among the primary areas on the STF for skiers and snowshoers looking for beginner to intermediate terrain. This North Highway 4 OSV area should be modified in the selected alternative to exclude the Cabbage Patch to Black Spring area and place a seasonal restriction on OSV use on Mattley Ridge. As noted earlier in these comments, Mattley Ridge should only be open for OSV use in the spring when Highway 4 is plowed.
- Although the Big Meadow Campground is not designated, road 7N02, the ski route to the Stanislaus River Overlook, is designated for OSV use because it falls within the Spicer OSV area. The Spicer OSV area should be modified in the selected alternative to exclude all of the Big Meadow non-motorized recreation area, including road 7N02 down to an elevation of 6400 feet.
- Includes both Osborne Hill and the Lake Alpine important non-motorized recreation zones within the Alpine OSV area. Both of these areas were previously closed to OSV use. Designating either of these areas is unacceptable for the non-motorized community. Designating the east

end of Lake Alpine not only reduces the non-motorized area around the lake but requires a long ski or snowshoe through a motorized area to get to non-motorized lands. The once non-motorized area along the east and south sides of Lake Alpine would be open for OSV use and the non-motorized route to Duck Lake would no longer exist.

- Includes all of the Herring Creek area within the Highway 108 OSV use area, failing to set any seasonal restrictions on OSV use in Herring Creek. As stated earlier in these comments, OSV use should only be allowed in Herring Creek in the spring once Highway 108 is plowed.

We appreciate that the STF at least recognizes 2 historic backcountry ski zones on the forest and that the Round Valley and Woodchuck Basin Near Natural Areas and Dodge Ridge area would be non-motorized in Alternative 5. However, these are the only places (that skiers and snowshoers actually visit) that are set aside for non-motorized winter recreation on the entire forest. Round Valley and Woodchuck Basin would be the only accessible non-motorized areas along the Highway 4 corridor. All other non-motorized areas are too far from parking areas to access by most skiers and snowshoers.

Alternative 5 designates portions of both the Eagle/Night and Pacific Valley Near Natural Areas for OSV use. As we've already discussed in these comments, designating near natural areas for OSV use, purely to satisfy a small contingent of the public and reward decades of unauthorized use, is not adequate justification for designation and would not comply with the OSV Rule's requirements to minimize impacts to other uses, wildlife, and the natural environment.

Like Alternative 4, this alternative fails to satisfy the minimization criteria and is not consistent with the current Forest Plan. Alternative 5 is unacceptable as it stands. Throughout our comments we have proposed several modifications to Alternative 5 that would make it an acceptable option.

CLIMATE CHANGE

It is well documented that climate change is leading to a reduced snow season in the Sierra Nevada. Not only is the season getting shorter, the physical footprint of where snow occurs is shrinking.[31] This means that in the future winter recreationists will have less space in which to recreate. Even in the high Sierra, where climate impacts are projected to be less severe than other locations, scientists predict that the snow season will decrease by at least 20 percent by 2050.[32] This change is already happening. As we've already discussed in these comments, recent research in the Tahoe region reveals that snow accumulation is now occurring significantly later than it did just 10 years ago, and the average winter snowline has moved significantly uphill.[33]

Climate change and accompanying changes in snow accumulation and snowpack on the STF will have significant repercussions for winter recreationists. As the total acreage covered by deep snow decreases there will be less space for recreationists to spread out to avoid conflict. Likewise, as traditional winter trailheads lose snow cover for all or part of the traditional winter season, use patterns will change.

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[31] Wobus et al. 2017. Projected climate change impacts on skiing and snowmobiling: A case study of the United States. *Global Environmental Change* 45 (2017) 1–14. https://www.sciencedirect.com/science/article/pii/S0959378016305556.

[32] *Id.*

[33] Hatchett et al. 2017. Winter Snow Level Rise in the Northern Sierra Nevada from 2008 to 2017. *Water*: *9*(11), 899; https://doi.org/10.3390/w9110899.

The STF winter travel plan should be forward-looking and proactively address the conflict and access issues predicted to occur as snowpack continues to retreat.

Recommendations:

- Do not designate low elevation areas (below 5,000 feet) for OSV use.
- Include a minimum snow depth restriction of at least 12 inches for OSV use on the forest.
- Make thoughtful designations based on quality of experience and minimization criteria rather than numbers of acres.

Economic Impacts

According to the STF's visitor use monitoring surveys and the DEIS, significantly more winter visitors to the STF engage in cross-country skiing than in snowmobiling. In the most recent NVUM survey cross-country ski visits were more than double snowmobiling visits. In addition, downhill skiing (which overlaps with backcountry skiing, as there is no NVUM category for backcountry skiing) is one of the most popular activities on the forest. Nationally, all forms of undeveloped skiing (backcountry skiing, splitboarding, and cross-country skiing) are on the rise[34] and the Forest Service and USDA both see backcountry skiing as a top activity in terms of growth, predicting participation increases between 55%-106% by 2060.[35] In contrast, as noted in the DEIS, OSV registrations in California are on the decline, and snowmobile sales nationally have declined precipitously over the past decade.[36] For these reasons, we find it curious that the economic impact section in the DEIS does not include details on the economic benefits of non-motorized winter recreation on the forest. In fact, non-motorized winter recreation is a primary factor in the region's winter economy and a key piece of the economic puzzle. The DEIS concludes that Alternative 3 would not measurably decrease OSV visitation to the ENF and therefore would not change the economic picture relative to today. However, if the DEIS more fully considered the economic benefits of non-motorized recreation, it might also conclude that improving recreation opportunities for skiers and snowshoers and minimizing user conflict, as Alternative 3 does, would significantly benefit the region's economy.

Monitoring and Enforcement

Regardless of exactly where the specific areas and trails are designated for OSV use, the Selected Alternative must include a clear plan for monitoring and enforcement. The DEIS includes monitoring procedures designed to: (1) measure effectiveness of designations in avoiding or minimizing resource damage; (2) measure public compliance with designations; (3) document enforcement of designations; and (4) measure use levels and patterns of use, and identify concentrated use areas and notes that site-

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[34] See https://winterwildlands.org/wwa/wp-content/uploads/2018/08/2018-Trends-and-Impact-Report.pdf

[35] Cordell, Ken H. (2010) Outdoor recreation trends and futures: a technical document supporting the Forest Service 2010 RPA Assessment. USDA Forest Service Southern Research Station. Available at: www.srs.fs.usda.gov/pubs/gtr/ gtr_srs150.pdf and USDA Forest Service. (2016). See also National Visitor Use Monitoring Survey Results; National Summary Report. Available at www.fs.fed.us/recreation/programs/nvum/pdf/508pdf2015_National_Summary_Report.pdf

[36] SnoWest Magazine, October 2017, pages 10-12. *Fronts and Forecasts. Snowmobile Sales: No Snow = Low Snowmobile Sales.* United States snowmobile sales dropped from 114,927 units in 1993 to 50,659 units in 2017. Although unit sales do not decrease every year, the overall trend is downwards. This trend is in part driven by low snow years.

specific controls (including increased on-site patrol personnel) will be implemented as needed annually.[37] The DEIS also states that the STF will enforce minimum snow depth requirements by monitoring with routine patrols and issuing citations if necessary. Likewise, the STF proposes to rely on routine patrols to document any signs of damage occurring to forest resources. Without dedicated funding to support these procedures we're concerned that this element of the OSV plan will fall by the wayside. In addition, if routine patrols do not occur in places, and at times, where non-compliance is most likely, these patrols will not be effective. The monitoring plan should include a baseline schedule so that the STF collects consistent data that can inform adaptive management as the plan is implemented. In addition, by setting a schedule for monitoring and patrols, the Forest Service will be better able to direct staff and resources to this critical aspect of the OSV plan.

To ensure better compliance with the OSV plan, especially in light of limited enforcement capacity, the STF must create an OSV plan that does invite unauthorized use. For example, in Alternative 5 the STF proposes to authorize OSV use to occur far up into Long Valley where it will be impossible to ensure that OSVs always stay within the designated road corridor and don't "high-mark" on the open slopes on both sides of the corridor. Likewise, Alternative 5 would open a portion of the Night Near Natural Area adjacent to Highway 108 at the very top of the Sonora Pass on the south side of the highway. Similar to the problem of containing snowmobiles within the area in Long Valley proposed for OSV use, this area at the top of the Sonora Pass would also be very difficult if not impossible to enforce to keep OSVs out of the rest of the Near Natural Area and adjacent Wilderness. We also have concerns about how the STF will enforce OSV restrictions around Highland Lakes and other areas where OSVs are known to trespass into non-motorized areas.

The STF must address funding – or the lack thereof – available to support the proposed mitigations, monitoring, and enforcement elements of the OSV plan. For example, although the Forest Service proposes to increase signage and compliance patrols to reduce or prevent OSV incursions into Wilderness, the DEIS does not discuss whether the STF has the resources necessary to support signage and patrols. Likewise, we would like to know if the STF actually has the resources needed to support education and enforcement measures, or whether the Forest Service hopes to work with partners to achieve at least some of these proposals.

We strongly support education, monitoring, and enforcement as tools for implementing the OSV plan. However, the STF must be honest with itself, and the public, about its capacity to actually carry out any of these proposed actions. The STF must design an OSV plan that it has the capacity to implement. If the Forest Service does not have the staff or resources educate the public about the new plan, monitor for compliance, and enforce OSV restrictions the plan will be nothing more than a nice idea. For it to be reality it must be designed such that it can be implemented. This includes not designating areas or routes that invite incursions into non-designated areas.

CONCLUSIONS

Thank you for the opportunity to submit comments at this stage in the Stanislaus OSV use designation process. We appreciate the substantial amount of work that has gone into this analysis, and we hope that our comments will provide helpful information for the Forest Service to develop a Selected

[37] DEIS at 42.

Alternative that meets the interests of all stakeholders and complies with the OSV Travel Rule. As currently written, Alternative 3 is the only Alternative we can support and is the only Alternative that minimizes conflict between recreational uses on the forest and OSV impacts to natural resources and wildlife. However, with the modifications we've described in these comments, Alternative 5 may prove to be a viable Selected Alternative.

In summary, we submit the following recommendations:

- Do not designate for OSV use any of the areas described in the section "Important human-powered winter recreation areas" starting on page 5.
- Only allow OSV use within Mattley Ridge and Herring Creek backcountry ski areas when the major OSV access points in their respective areas are closed due to spring plowing.
- Do not designate for OSV use any portion of the existing Near Natural Areas, Recommended Wilderness Areas, or Special Interest Areas, or reduce any of these areas in size by amending the current Forest Plan.
- Do not designate low elevation areas (below 5,000 feet, and the Interface Area) for OSV use.
- Mandate a minimum snow depth of 12 inches for OSV travel on the forest, with greater depth restrictions in Stanislaus Meadow and Highland Lakes (24 inches), and in areas with soils that are particularly prone to compaction (18 inches).
- Set an OSV use season of December 1 – April 30 for most areas of the forest and in sensitive wildlife areas.
- Designate Highway 108 as a PCT crossing point. Do not designate other areas adjacent to the PCT for OSV use.
- Make thoughtful designations based on quality of experience and minimization criteria rather than numbers of acres open or closed for OSV use.
- Incorporate adaptive management into the travel plan so that the plan is flexible and responsive to "abnormal" winters and snow conditions.

Sincerely,

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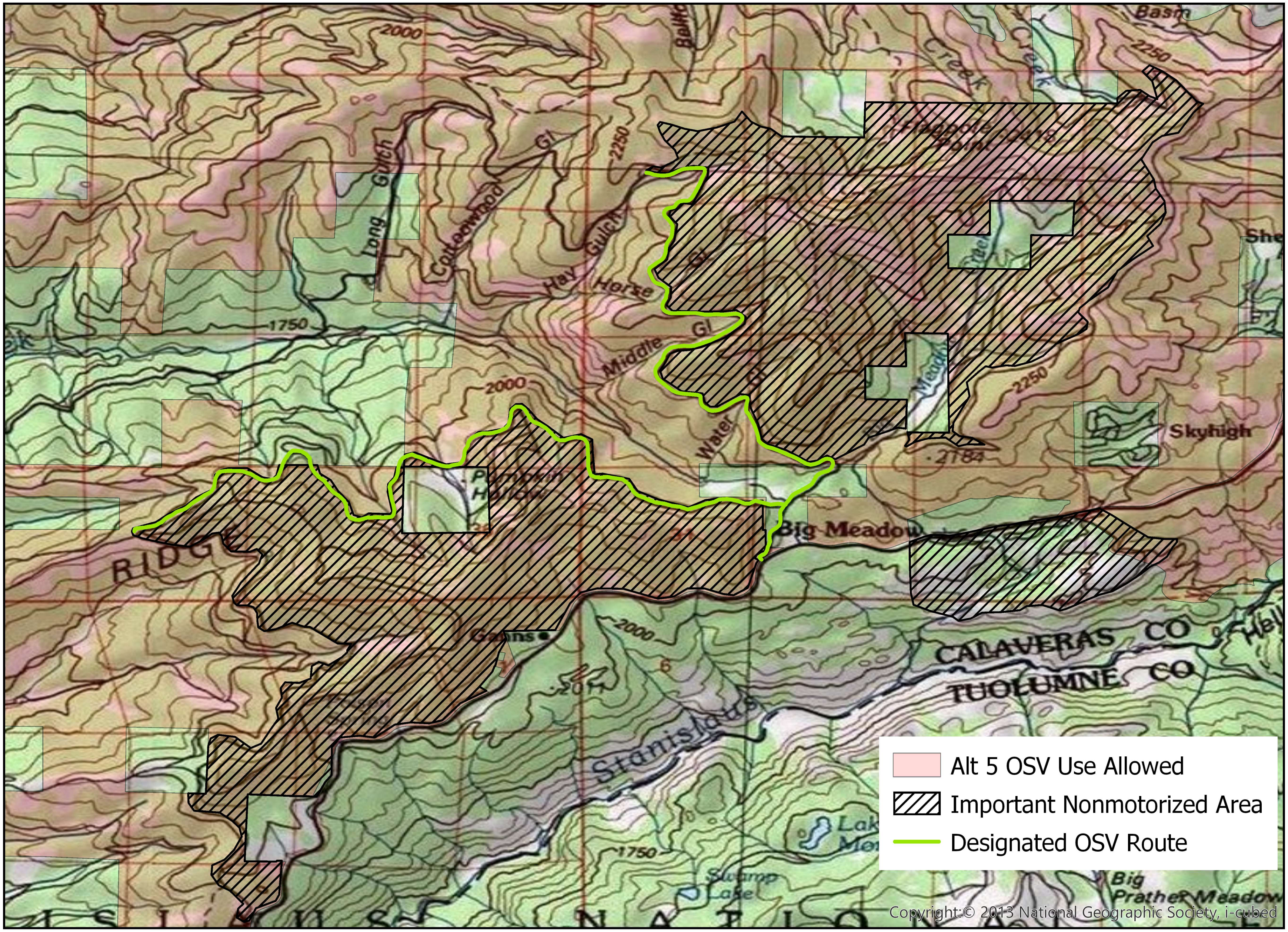
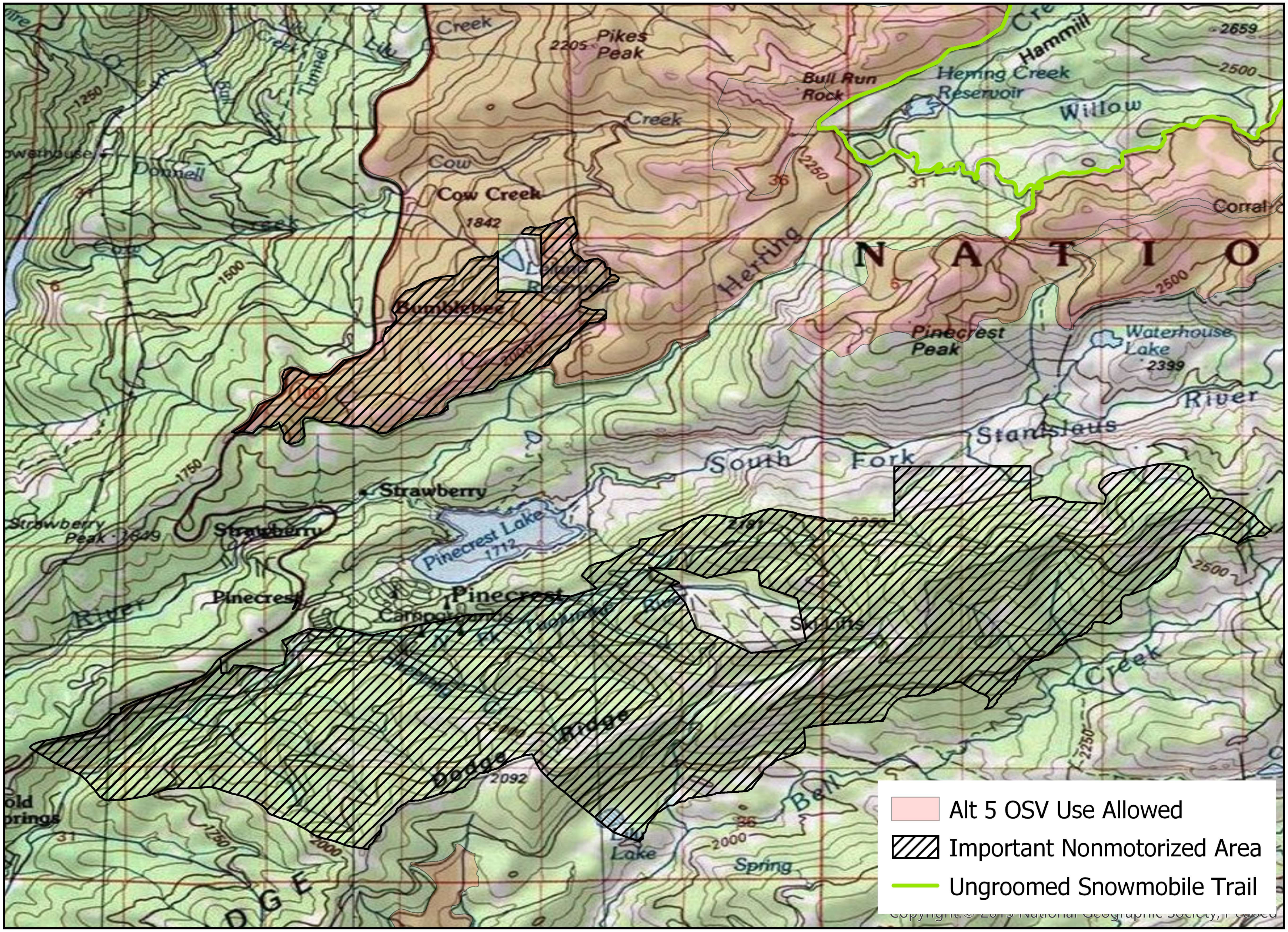
Cabbage Patch, Mattley Ridge, Big Meadow
Important Non-Motorized Areas



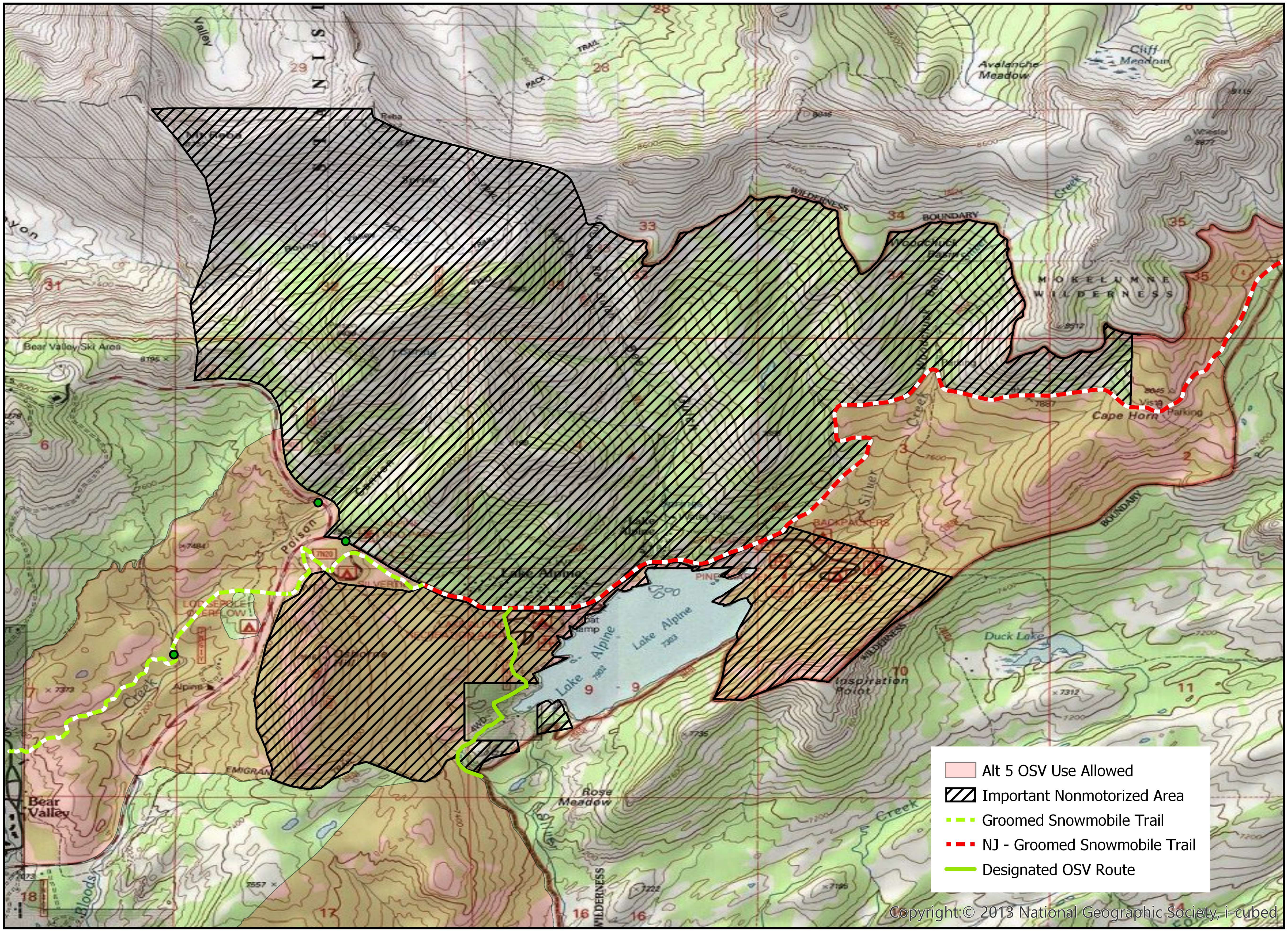
Dodge Ridge, Herring Creek

Important Non-Motorized Areas



Round Valley, Osborne Hill, Lake Alpine

Important Non-Motorized Areas



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Article

Winter Snow Level Rise in the Northern Sierra Nevada from 2008 to 2017

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Abstract: The partitioning of precipitation into frozen and liquid components influences snow-derived water resources and flood hazards in mountain environments. We used a 915-MHz Doppler radar wind profiler upstream of the northern Sierra Nevada to estimate the hourly elevation where snow melts to rain, or the snow level, during winter (December–February) precipitation events spanning water years (WY) 2008–2017. During this ten-year period, a Mann-Kendall test indicated a significant ($p < 0.001$) positive trend in snow level with a Thiel-Sen slope of 72 m year^{-1}. We estimated total precipitation falling as snow (snow fraction) between WY1951 and 2017 using nine daily mid-elevation (1200–2000 m) climate stations and two hourly stations spanning WY2008–2017. The climate-station-based snow fraction estimates agreed well with snow-level radar values ($R^2 = 0.95$, $p < 0.01$), indicating that snow fractions represent a reasonable method to estimate changes in frozen precipitation. Snow fraction significantly ($p < 0.001$) declined during WY2008–2017 at a rate of 0.035 (3.5%) year^{-1}. Single-point correlations between detrended snow fraction and sea-surface temperatures (SST) suggested that positive SST anomalies along the California coast favor liquid phase precipitation during winter. Reanalysis-derived integrated moisture transported upstream of the northern Sierra Nevada was negatively correlated with snow fraction ($R^2 = 0.90$, $p < 0.01$), with atmospheric rivers representing the likely circulation mechanism producing low-snow-fraction storms.

Keywords: atmospheric rivers; California; Nevada; precipitation; Sierra Nevada; snow; snow level; water resources

1. Introduction

As the climate warms, the partitioning of snowfall to rainfall in snow-dominated mountain watersheds is likely to change [1–5]. Changes in precipitation phase alter seasonal snowpack dynamics, ecological processes, peak streamflow timing, and winter flood hazards [5–7]. These changes present different challenges for water supply forecasting and reservoir operations [8], particularly in states that depend upon snow-derived water resources and are at risk for winter flooding [9,10]. Continued climate change, increased drought risk [11], and more intense extreme precipitation events [12] will necessitate adaptive water management strategies.

During the past seven water years (WY; 1 October–30 September), California and Nevada experienced the full range of hydroclimate extremes. Precipitation reductions during a multiyear drought from WY2012 to WY2015 were found to be consistent with average conditions that were estimated during the extreme and persistent Medieval droughts [13], with anomalous positive temperature anomalies enhancing drought severity [14]. Conversely, WY2017 was the wettest year in the past century and followed a near-average WY2016. These wide-ranging hydroclimatic conditions provide incentive to study the physical mechanisms that may be influencing hydrologic variability in the Sierra Nevada, as this knowledge can be used to inform and prioritize adaptation strategies for sustainable water management under a changing climate [15].

This study focuses on the northern Sierra Nevada, a 150 km wide north-south trending mountain range with crest elevations ranging from 2000 to 3000 m (Figure 1). Approximately 50% of annual precipitation occurs during the winter months (December–February; hereafter winter) [16]. The orientation of the northern Sierra Nevada orthogonal to prevailing westerly winds creates significant orographic precipitation effects that influence precipitation magnitude and spatial distribution (e.g., [17] and references therein). Water stored as snow that accumulates during the cool season (November–March) subsequently melts and runs off (typically during April–July) and provides the primary source of streamflow in the American, Yuba, Truckee, and Feather River basins (Figure 1). All of these basins are managed for multiple purposes, including flood control, and to meet ecological and human consumptive demands. The relatively low elevation of these basins makes them susceptible to changes in precipitation phase due to warming [18], which has significant implications for winter flooding [9,19] and warm season water availability [15]. Because of the importance of the northern Sierra Nevada for water resources and flood prevention in California and Nevada, a novel network of hydrometeorological measurements exist upstream of the Sierra Nevada [20] and offer a unique means to explore hydroclimatic change in this region.

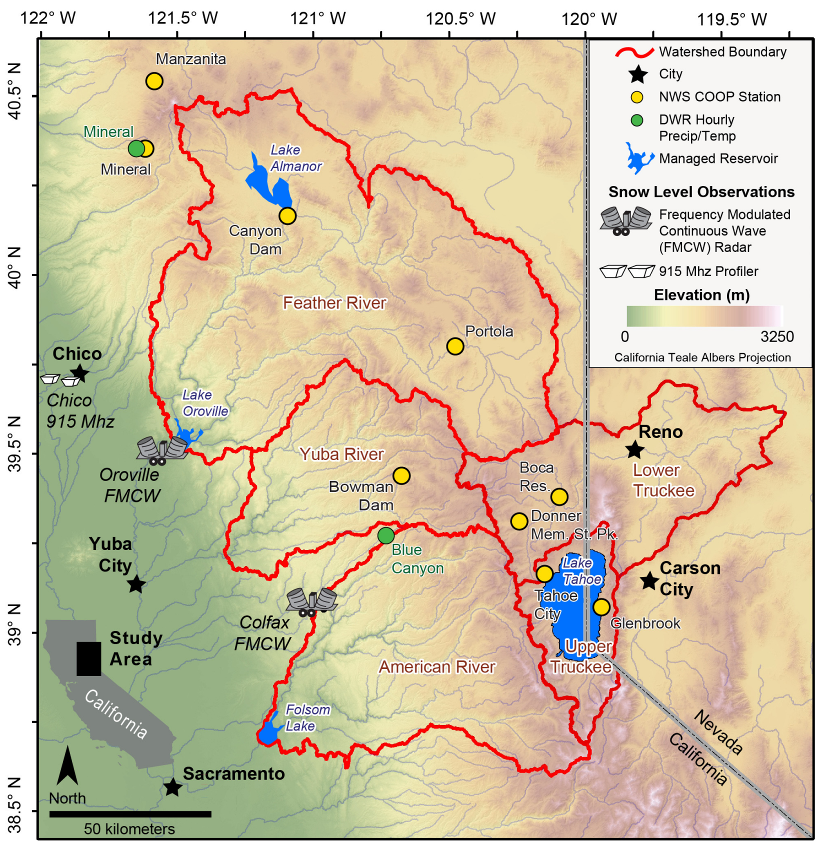

Figure 1. The northern Sierra Nevada study area.

Snow level, or the elevation where snow melts to rain, is a primary control on the sensitivity of mountain snowpack accumulation to climate warming during precipitation events [21]. The brightband elevation, or the altitude of maximum radar reflectivity in the melting layer, provides an adequate estimate of the snow-level height and thus the phase of precipitation for given elevations [22,23]. We employed measurements of brightband elevations using a network of snow-level sensing radars established for real-time hydrometeorological monitoring in California to evaluate observed snow-level changes during the past 10 winters in the northern Sierra Nevada (Figure 1) in order to address the following objectives: (1) Test the hypothesis that snow levels have been rising during the past decade; (2) See if consistency exists between the changes in inferred precipitation phase deduced from snow-level radar observations and those estimated by an empirical relationship at weather stations developed by Dai [24]; and, (3) Explore plausible physical mechanisms controlling precipitation phase using reanalysis products and observational data, with the hypothesis that atmospheric rivers will strongly control snow fraction and snow level.

2. Materials and Methods

2.1. Snow Level Radar

We estimated snow levels on the basis of brightband heights measured at hourly intervals from December 2007 through February 2017 from a 915-MHz Doppler radar wind profiler [25], located in Chico, California (Figure 1). These measurements were complemented by brightband elevations that were estimated by frequency-modulated, continuous-wave, snow-level radars [26] at Oroville and Colfax, California (Figure 1), spanning the meteorological winters from December 2010 (December 2011 for Oroville) to February 2017. The data for all three radars were obtained from the Earth Systems Research Laboratory [27]. The radar data and algorithm used to convert Doppler velocity and radar reflectivity into melting elevation are described in White et al. [28,29].

The brightband height data from the snow-level sensing radars as well as the precipitation and temperature observations from the weather stations (described in Section 2.2) were examined to identify possible outliers. These included snow levels above 4000 m and temperatures above 30 °C or below −15 °C, while hourly precipitation measurements greater than 50 mm were filtered to eliminate erroneous measurements. We applied a diurnal correction to account for over- and under-estimation to radar-derived snow levels [22]. We shifted snow-level values during daylight hours (9:00 A.M.–5:00 P.M. LST) upward 100 m for Chico and 20 m for Oroville and Colfax. We shifted snow-level values lower during nighttime hours (200 m for Chico and 150 m for Oroville and Colfax). We also applied a latitudinal correction [22] to Colfax consisting of a 20 m increase to facilitate comparisons with Oroville and Chico. Our trend analysis results did not change significantly with or without applying these corrections because these changes were systematically applied. The snow-level sensing radars are located upstream of the Sierra crest (Figure 1), therefore the brightband heights should be interpreted as the maximum values given potential mesoscale lowering of the snowline [21,30].

2.2. Station-Based Observations

We obtained hourly temperature and precipitation values from alter-shielded weighing gauges operated by the California Department of Water Resources [31] from two mid-elevation stations: Mineral, California (1511 m), and Blue Canyon (1609 m) (Figure 1). These data span the winters of 2008 through 2017 and were included to compare snow-fraction estimates made at high temporal resolution against snow-level radar observations. To examine the relationship between lower temporal resolution observations and snow-level radar observations as well as extend the snow fraction estimates back further in time, we also used daily minimum and maximum values of temperature and precipitation from nine National Weather Service Cooperative Observer (COOP) [32] stations with >85% complete records [33]. Data from these stations, that are in the northern Sierra Nevada snow belt (>1200 m;

Figure 1), spanned December 1950 through February 2017. In order to develop a relationship between observed precipitable water and snow levels, hourly GPS-observed precipitable water data at Petaluma, California was acquired from SuomiNet [34]. We compared precipitable water data only during hours (n = 1249) when snow-level observations were present for six hours during a calendar day. The reported correlation of determination ($R^2 = 0.6$) was maximized with a three-hour lag.

The fraction of precipitation falling as snow (hereafter, snow fraction) was estimated based upon the approach developed by [24] and employed by [35]. We summed hourly precipitation totals at 0.5 °C intervals from −15 °C through 25 °C with respective observations from Mineral and Blue Canyon. We calculated conditional frequencies of snow at each 0.5 °C interval using the hyperbolic tangent function developed by [24] but with parameters estimated for the Sierra Nevada ecoregion by [35]. The conditional probabilities can be interpreted as likelihoods of snow at given temperatures [22]. We multiplied the probability of snow by the total precipitation at each temperature interval. We then divided the sum of this value by the total precipitation to calculate the snow fraction for each water year. This calculation was repeated for the nine COOP stations at daily time steps for the WY1951–2017 period but with maximum temperatures [35]. We report the median snow fraction calculated as an average of median values from the nine stations.

2.3. Tests for Trend

To test the hypothesis that non-zero trends in snow level and snow fraction existed during the past decade (between WY2008–2017), we used the Mann-Kendall [36,37] test that was modified to account for serial correlation [38] and reported the Thiel-Sen slope [39] for this period.

2.4. Large-Scale Controls on Snow Level and Snow Fraction

We used 1° gridded monthly sea surface temperatures (SST) from the COBE-SST reanalysis [40] and 2.5° gridded output of daily precipitable water and 700 hPa geopotential heights from the National Center for Environmental Prediction (NCEP) reanalysis [41] from December 1950 through February 2017. We used integrated vapor (moisture) transport at a grid point that was located upstream of the northern Sierra Nevada from the NASA Modern Era Retrospective Analysis (MERRA) [42] and a catalog of atmospheric rivers developed using the atmospheric river detection method of Rutz et al. [43] for the winters spanning WY1981–2017.

To explore a plausible, large-scale, physical mechanism favoring precipitation-phase changes between snow and rain, we performed single-point correlations [16] to calculate Pearson's correlation coefficient (r) between each SST grid point (averaged over winter) and the time series of the nine-station COOP median snow fractions from WY1951 to 2017. We removed linear trends from each time series prior to performing correlations [44]. We only noted grid points as statistically significant when the p-value of the correlations satisfied the false discovery rate test [45] at the alpha = 0.05 level.

To further investigate an atmospheric circulation mechanism driving observed high and low snow fraction events, we used the Tahoe City COOP (Figure 1) to identify precipitation days exceeding the 90th percentile of non-zero precipitation days. These days were subset into warm (>3 °C) and cold (<−2 °C) events. We selected Tahoe City because it is near many important river basins in our study area and because the observed snow-fraction variability from this station reasonably approximated the nine-station median ($R^2 = 0.67$, $p < 0.01$). Under the two sets of temperatures, the snow-fraction calculation [24] implies that the cold days will be dominated by frozen precipitation, whereas warm days will result in the melting of the existing snowpack [22]. For the respective wet warm and cold combinations, we composited NCEP precipitable water and 700 hPa geopotential height fields over the eastern North Pacific domain. Next, to provide a continuous examination of the role of moisture transport on snow fraction, we correlated MERRA-derived integrated vapor transport with daily snow fraction bins from 0 to >0.95, with a bin size equal to 0.05 (or 5%). The number of atmospheric rivers identified by the method of [43] was counted for each bin.

3. Results

3.1. Snow Levels and Snow Fractions

Snow levels at Chico were variable across years during the observed record (Figure 2). The lowest median value was observed during WY2009, and the highest values were observed during the peak drought years of WY2014–2015 (Figure 2). A significant non-zero trend ($p < 0.001$) during WY2008–2017 was identified with a Thiel-Sen slope of 72 m year^{-1} (Figure 2). This trend was broadly consistent with the WY2011–2017 slopes at Oroville and Colfax (approximately 50 m year^{-1}). Observed snow levels at Chico and Colfax were positively correlated (R^2 = 0.84, $p < 0.01$); Figure 3). Snow fractions at Blue Canyon and Mineral were moderately well correlated (R^2 =0.57, $p < 0.05$) and varied from as high as 0.55 to as low as 0.19. The correlation between Chico snow level and Mineral snow fraction was −0.72 ($p < 0.01$). The average 2008–2017 median snow level at Chico was 1640 m. Separating the past decade into two, five-year halves, WY2008–2012 had an average median of 1410 m, while WY2013–2017 had an average median of 1860 m. A Wilcoxon rank sum test calculated using hourly values indicated that the WY2008–2012 and WY2013–2017 medians were significantly different ($p < 0.0001$).

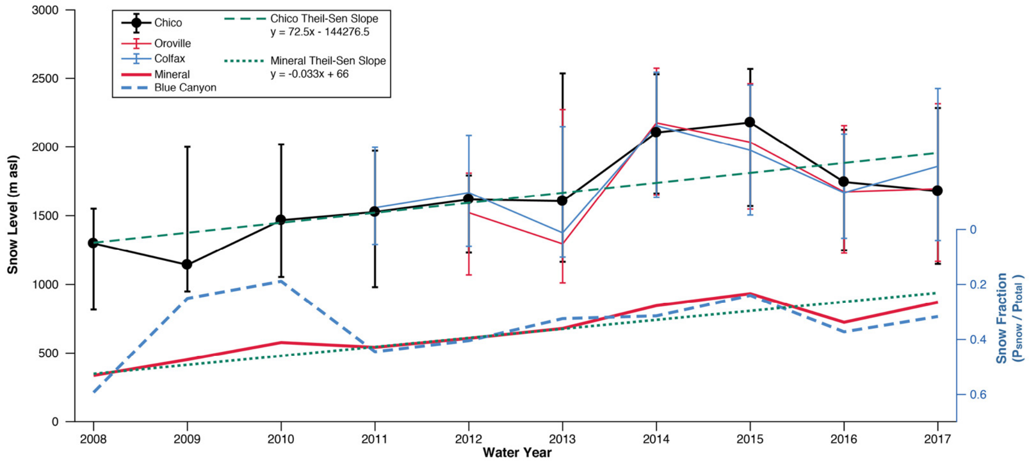

Figure 2. Water year (WY) 2008–2017 snow levels observed by the Chico radar and snow levels observed by the Oroville (WY2012–2017) and Colfax radars (WY2011–2017). Capped bars designate upper and lower quartiles with black dots showing Chico median values. Right y-axis: Snow fractions at the Mineral and Blue Canyon hourly precipitation stations. Note the reversal of the right y-axis such that an upward slope indicates a decrease in snow fraction.

Consistent with the rise in snow level shown by snow-level radar, we observed a negative trend in snow fraction at both Blue Canyon and Mineral (Figure 2), but only the slope at Mineral was significant ($p < 0.001$). With the exception of WY2009–2010, snow fractions at Blue Canyon and Mineral were well correlated, and varied from as high as 0.55 to as low as 0.19. Snow fraction declined at a faster rate at Mineral (−0.033 year^{-1} or −3.3% year^{-1}) than at Blue Canyon (−1.4% year^{-1}). Assuming an average environmental lapse rate over all land of 5.1 °C per 1000 m [24] and on the basis of the modified equation for precipitation phase [24,35], the 450 m increase in average median snow levels between the five-year periods spanning WY2008–2012 and WY2013–2017 (Figure 2) equates to a warming of approximately 2.3 °C. At Mineral, 50% of precipitation fell on days below 1 °C. Therefore, an increase of 2.3 °C reduced the snow fraction by about 25%. This value falls between the linear estimate of snow-fraction change during the 10-year period (33%) and the difference in average snow fraction between these periods (15%). The observed mean annual winter temperature during hours when precipitation was recorded at Mineral rose by 1.6 °C between these periods. This is lower but broadly consistent with the estimated warming from median snow levels that were found using an average environmental lapse rate.

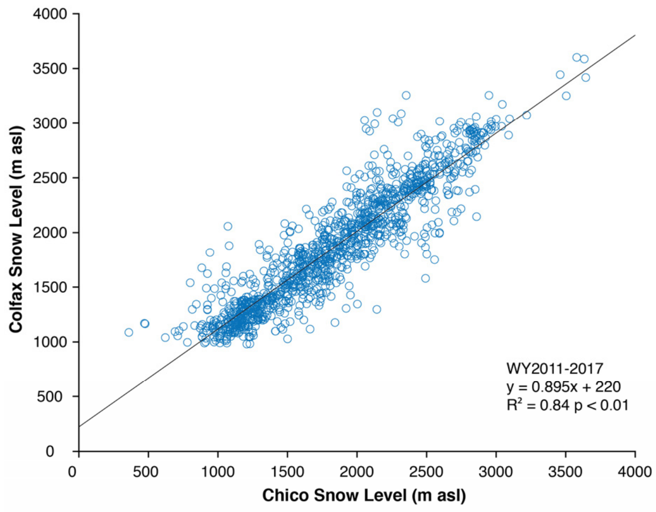

Figure 3. Scatterplot of hourly Chico versus Colfax observed winter snow levels between WY2011 and 2017. Outlier points exceeding 1000 m difference between stations were removed for a total of n = 1195 observations.

Between WY2008 and WY2017, the COOP snow fraction (Figure 4) and median Chico snow level were negatively correlated ($R^2 = 0.95$, $p < 0.001$; calculated using Spearman's rank correlation due to the shorter time period). The past ten years of COOP data demonstrated decreases in snow fractions (Figure 5) that are consistent with the increasing snow levels observed by snow-level radar and decreasing snow fractions at hourly stations (Figure 2). Of the 67 years analyzed, the median snow fraction varied substantially among years from more than 0.4 in WY1971 to less than 0.1 in WY2015 (Figure 5). Wet winters can have low (e.g., WY1956, WY1997, WY2017) or high (e.g., WY1969 and WY1993) snow fractions. Dry winters also can have either low (e.g., WY1991 and WY2015) or high (e.g., WY 1965 and WY1985) snow fractions. These results are consistent with [46], with no significant correlation between winter precipitation and snow fraction. The snow fraction slope of -3.5% year^{-1} ($p < 0.0001$; Figure 5) during WY2008-2017 was the steepest negative slope of any observed in the 10-year period from WY1951–2017, and its Thiel-Sen slope was consistent with the declines estimated for Mineral (-0.035 versus -0.033).

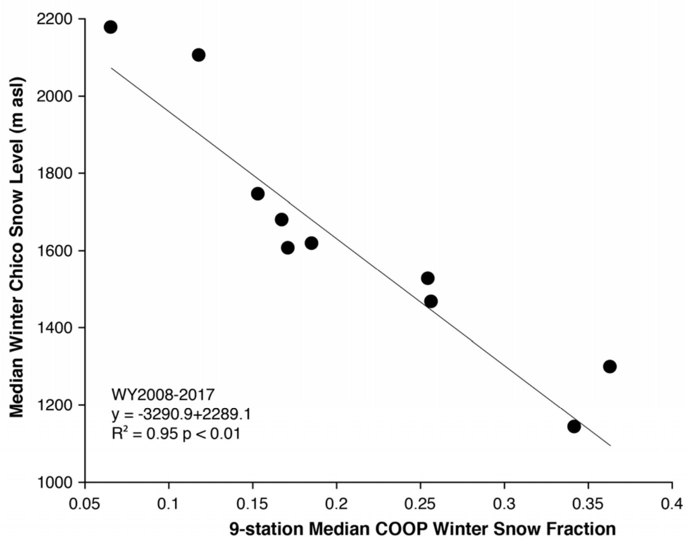

Figure 4. Scatterplot of winter median Chico observed winter snow levels versus winter median National Weather Service Cooperative Observer (COOP) snow fractions between WY2008 and 2017.

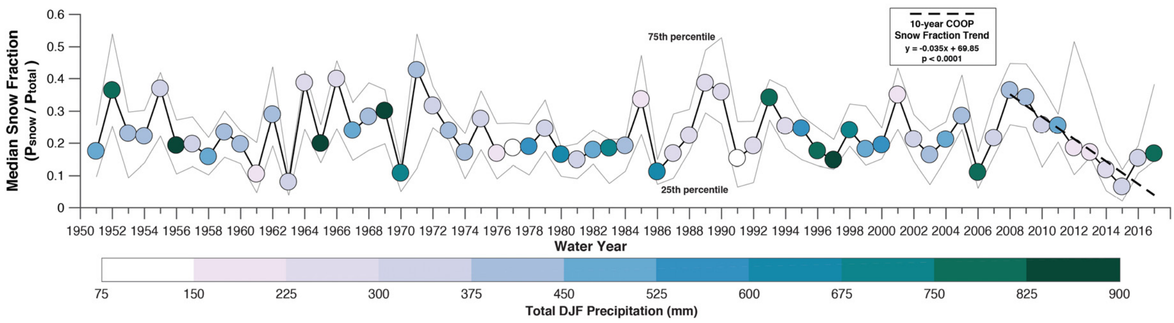

Figure 5. Median winter snow fraction for nine COOP stations between WY1951 and 2017. Dots are colored by total winter precipitation. The grey lines indicate the upper and lower quartile values.

3.2. Seasonal and Event Relationships Between Large-Scale Circulations, Snow Level, and Snow Fraction

At the seasonal timescale, single-point correlations between the time series of COOP-derived snow fractions and SSTs broadly resembled an expression of the Pacific Decadal Oscillation (PDO; Figure 6a) [47] and are negatively correlated (R^2 = 0.13, p < 0.01) with the winter PDO index [48]. No correlation existed (R^2 = 0.01, p = 0.354) between September-November multivariate El Niño-Southern Oscillation (ENSO) index [49] and subsequent winter snow fraction. The only significant negative correlations between snow fraction and SST anomalies (R^2 > 0.25, p < 0.05) were found immediately offshore of California. Following [16], we produced a time series by averaging SST anomalies in this region for comparison against snow-fraction anomalies. The resulting time series illustrates the generally negative correlation between SSTs and snow fractions (Figure 6b; note reversal of right y-axis) with occasional exceptions (e.g., WYs 1973 and 2013). The correlations were the strongest when no lag was applied (i.e., using December–February SSTs instead of November–January SSTs). Positive SST anomalies offshore of California were associated with reductions in observed winter snow fractions.

Composites of precipitable water and 700 hPa geopotential height for warm, wet days (Figure 6c) at Tahoe City demonstrated a coherent, southwest-northeast oriented precipitable water plume in the southeastern subtropical Pacific that exceeded 25 mm with positive precipitable water anomalies (calculated as differences between composited events and mean 1981–2010 winter precipitable water) exceeding 8 mm (Figure 6e). The shape and orientation of this composite moisture plume resembled an atmospheric river [50]. This agreed with the negative correlation between MERRA-derived integrated vapor transport (R^2 = 0.90, p < 0.01; calculated using Spearman's rank correlation) and the finding that the four lowest snow fraction bins (0–0.2) had nearly twice the number of identified atmospheric rivers as all the other bins combined (302 versus 170; Figure 7a). This was also consistent with the positive relationship between GPS-observed precipitable water at the coast and Chico snow level (R^2 = 0.6, p < 0.01; Figure 7b). Warm and wet days corresponded with zonal flow, a negatively tilted trough in the northeastern Pacific, and an omega block over the Bering Sea (Figure 6c). These features are similar to composites of leeside flood-producing storms with high snow levels [9]. The cold and wet days had a weaker composite signal of subtropical moisture (<20 mm precipitable water) between Hawaii and California (Figure 6d). Precipitable water anomalies ranged from +2 mm offshore of southern California to −3 mm near 30 °N, 140 °W with a broad area of negative precipitable water anomalies (−4 to −8 mm) in the eastern Gulf of Alaska and northeastern Pacific (Figure 6f). These composite days demonstrated a meridional flow with a deeper negatively tilted northeastern Pacific trough and an amplified ridge centered near 160 °W (Figure 6d).

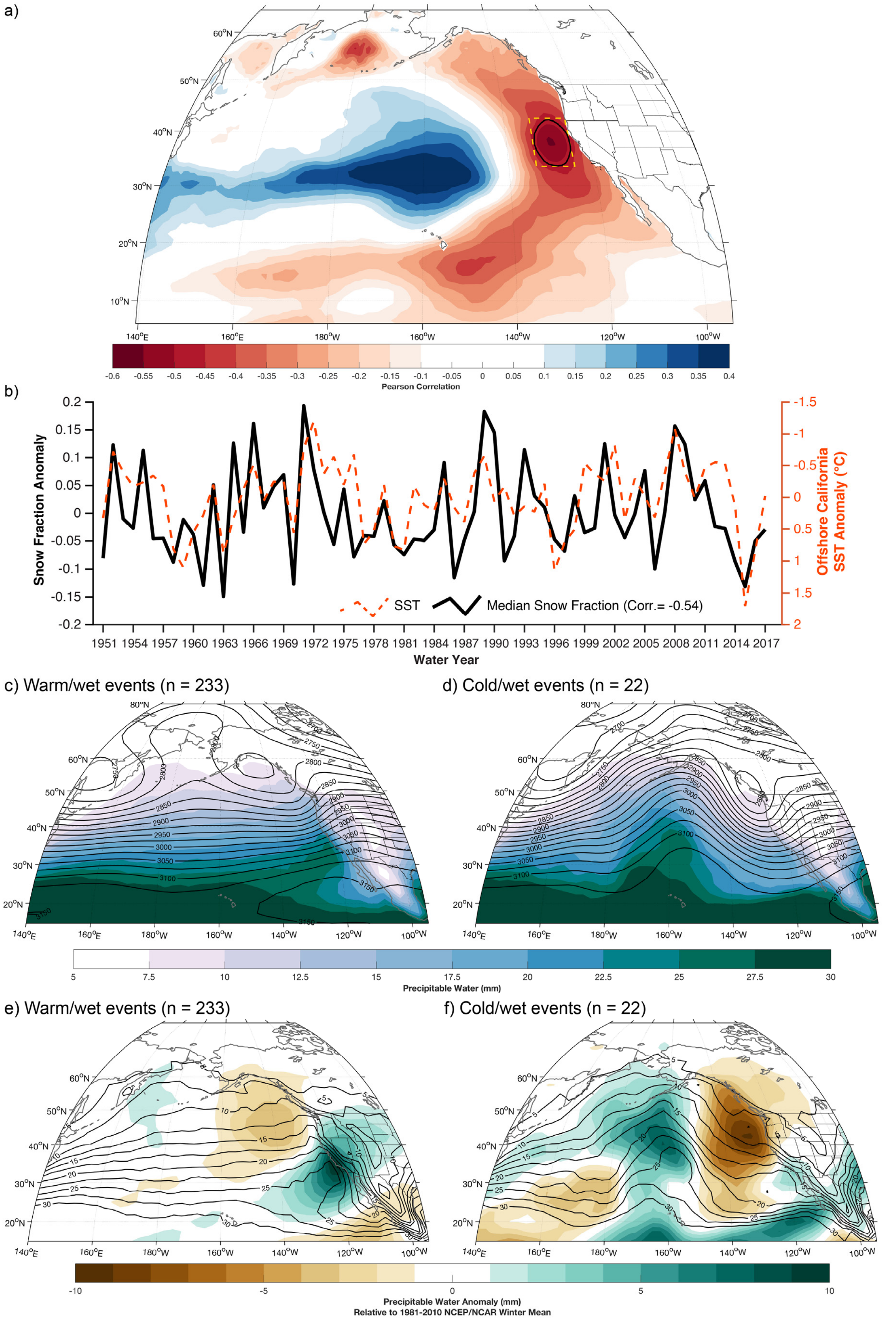

Figure 6. (**a**) Single-point correlations between winter northern Sierra Nevada median snow fraction and sea surface temperatures (SSTs) during WY1951–2017. Black contours encircle grid points at which

correlations were statistically significant ($p < 0.05$). (**b**) Time series of northern Sierra Nevada median snow fraction anomaly (right y-axis) and average SST anomalies (left y-axis) within the gold box shown in (a). Composites of National Center for Environmental Prediction (NCEP) precipitable water (filled contours) and 700 hPa geopotential heights for 90th percentile winter precipitation events at Tahoe City (Figure 1) on warm days (maximum temperatures > 3 °C) (**c**) and cold days (maximum temperatures < −2 °C). (**d**) Composite precipitable water (contours, interval 2.5 mm) and precipitable water anomalies (filled contours, in mm) calculated as differences between the (**e**) warm/wet composite days and (**f**) cold/wet composite days and the long-term mean 1981–2010 winter precipitable water output from the NCEP reanalysis.

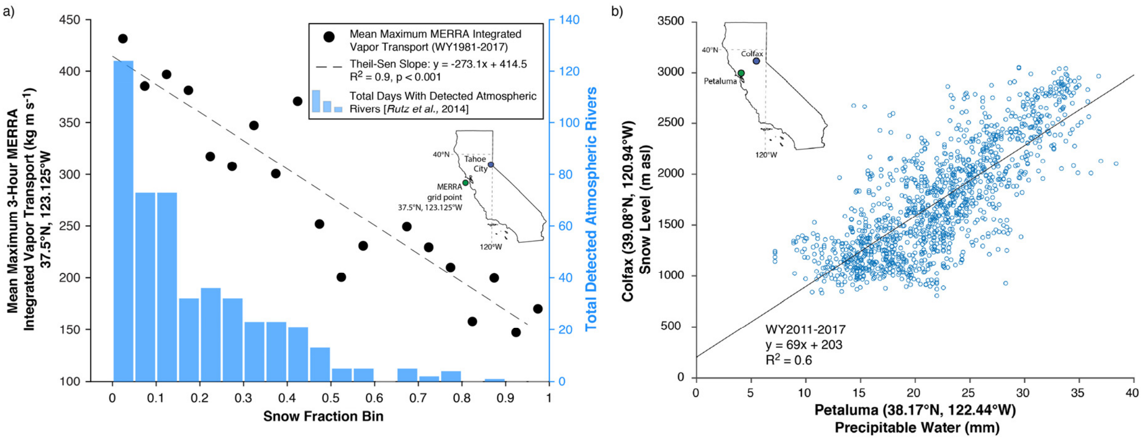

Figure 7. (**a**) (Left y-axis): Scatterplot of mean maximum Modern Era Retrospective Analysis (MERRA) [42] integrated vapor transport (kg·m·s^{-1}) at an upstream grid point from Tahoe City (note inset maps) for each 0.05 (5%) bin of snow fraction (e.g., 0–0.49, 0.5–0.99, . . .). (Right y-axis): Bar chart of total atmospheric rivers detected using the Rutz et al. [43] algorithm for each snow fraction bin. MERRA output used spans the period 1 January 1980 to 28 February 2017. (**b**) Scatterplot of observed precipitable water at Petaluma, California (near the California Coast) and snow level at Colfax, California between 2011 and 2017.

4. Discussion

We used snow-level radar to identify a trend in median snow levels between WY2008 and 2017 in the northern Sierra Nevada (Figure 2) with an estimated annual rate of 72 m year^{-1}. This rise coincides with decreases in snow fractions derived from both hourly (Figure 2) and daily (Figure 5) weather station observations. The consistency between changes in inferred snow fraction at stations (Figures 2 and 5) and those that were estimated by applying an average environmental lapse rate to snow-level changes (Figure 2) gives us confidence that the snow-level radars are accurately recording a robust change in precipitation phases, hence supporting our first objective. The significant positive correlation ($R^2 = 0.95$, $p < 0.01$) between snow levels and snow fractions provides confidence that the snow-level radars are accurately recording precipitation phases. The correlation also affords confidence that the empirically-based estimate of snow fraction represents a reasonable means to estimate past or future changes in precipitation phase (e.g., [51]), thus supporting our second objective. These conclusions are despite uncertainties that are posed by storm-scale variability [22], potential bias in snow-fraction calculations because of precipitation gauge collection efficiency [52,53], and errors in snow-level observations. The ability to estimate changes in precipitation phase operates under the assumption that the empirical relationship to calculate snow fraction [15] remains stationary in time and is not sensitive to rain and snow transitions or spatiotemporal variability [46]. Further improvement in the snow-fraction calculations could be obtained by developing site-specific parameter values [46] and using additional observations [5].

Note that much of our study period corresponded with a period of notable hydroclimatic extremes. A severe drought during WY2012–2015 [12,13] was followed by subsequent average and record wet years during WY2016 and WY2017, respectively. The 67-year calculation of nine-station median snow fractions indicated that high or low snow fractions (Figure 5), and thus snow levels (Figure 2) could occur during either wet or dry winters, as consistent with [42]. We speculate that dry, low-snow-fraction years (e.g., WY2015) would have a more severe impact on hydrologic systems than a dry, high-snow-fraction year (e.g., WY1989). Continuing work seeks to more closely examine streamflow responses to winters with varying combinations of precipitation total and precipitation phase distributions. These years may provide analogs to possible future climate regimes that can inform water management strategies [14].

Our third objective was to evaluate the role of circulation (atmospheric rivers) and regional climate conditions (SSTs) in influencing snow fraction and snow levels. Our composite analysis indicating that low-snow-fraction storms have stronger (anomalous positive) moisture plumes (Figure 6c,e) is consistent with rain-on-snow climatologies [9,54]. Further evidence is provided by the negatively correlated (R^2 = 0.90, $p < 0.001$) relationship between mean-maximum-upstream, MERRA-derived vapor transport and Tahoe City snow fraction (Figure 7a). The positive relationship (R^2 = 0.6, $p < 0.01$) between observed precipitable water near the California coast and the three-hour lagged snow level at Colfax (Figure 7b) supports the notion that storms with greater precipitable water (Figure 6c) and moisture transport (Figure 7a) are associated with higher snow levels. This relationship is consistent with [55] although our correlation is weaker, perhaps because of the distance between Colfax and Petaluma. Overall, these results support the hypothesis that atmospheric rivers are important drivers of snow level and snow fraction variability at the event scale.

As found in field studies [56] and modeling experiments [57], anomalous positive SSTs offshore of continents modify air masses by contributing upward heat flux and decreasing static stability, leading to increases in downstream precipitation. At longer (seasonal) timescales, we observe that the negative correlations between snow fraction and SSTs offshore of California (Figure 6a,b) are located near the primary region of storm track activity that is correlated with winter California precipitation [16]. The warming effect of SSTs on the warm sector of the cyclone may enhance baroclinicity [58] and subsequently increase low-level winds and moisture fluxes (Figure 7a) that promote greater orographic precipitation [59]. Atmospheric rivers making landfall in California during warm coastal SST regimes are associated with stronger southerly winds and enhanced poleward moisture transport [60]. During warm (low snow fraction) storms, the large-scale zonal flow promotes the advection of warm, moist subtropical air into the southwestern U.S. (Figure 6c,e), with atmospheric rivers largely contributing to low-snow-fraction storms (Figure 7a).

Additional alternative hypotheses of the mechanisms producing snow level rise are the subject of ongoing study. Coupled ocean-atmosphere modeling approaches could help disentangle the relationship between wetter and warmer storms that result from increases in saturation vapor pressure due to temperature rise and those undergoing modifications from ocean heat fluxes (e.g., [61]) or poleward advection of subtropical airmasses [60]. Additional research is also necessary to better understand the relative roles of tropical-extratropical interactions (e.g., ENSO and the Madden-Julian Oscillation [62,63]) that influence winter snow level and snow fraction at timescales varying from seasonal to individual events.

Because of the short duration of analyzed data, we recommend further evaluation of observations to examine whether the apparent upward-snow-level trend continues. This represents a primary limitation of our study. We have provided evidence that the snow-level radar and snow- fraction estimates appear to offer reasonable metrics to observe and evaluate precipitation phase change in snow-dominated watersheds [1,5,28–30]. These changes will have marked effects on warm season streamflow [4], especially during drought years [13]—with negative implications for urban, ecological, and agricultural water demands [13–15,64]. If such a connection between SSTs, moisture plume strength, and snow fractions does exist, it suggests that snow accumulation may further decline with continued regional warming. This warming is expected to produce wetter, stronger atmospheric rivers [12], that in turn will contribute to shallower snowpacks and a greater potential for rain-on-snow events and flooding [9,10,54,55]. These changes also may limit drought recovery during occasional wetter years that occur during persistent droughts [65]. Warming background temperatures combined with changes from snow to rain leads to decreased water availability in spring and throughout the warm season [4,66–68]. Our findings thus suggest another mechanism that may act in tandem with background warming to amplify the loss of snow-derived water resources in the western U.S. [69,70]. This may be amplified if northeast Pacific SST variability and persistence increase, thus leading to longer duration episodes of anomalous warm SSTs [47] that support decreased snow fractions (Figure 6a,b).

5. Conclusions

We identified a statistically significant positive (negative) trend in winter snow levels (snow fractions) in the northern Sierra Nevada during the winters between WY2008 and 2017. We found consistency between increases in the elevation of winter snow levels measured by snow-level sensing radars and estimated snow fractions. Atmospheric rivers are predominantly associated with low-snow-fraction storms, and anomalously warm coastal SSTs appear to favor lower-snow-fraction winters—perhaps by enhancing the upward heat flux during atmospheric river landfalls and promoting zonal flow regimes that increase the advection of warm subtropical air into the northern Sierra Nevada, leading to storms with higher snow levels. This hypothesis will require modeling experiments to test its validity. If true, it suggests that continued increases in sea-surface temperatures and increased frequencies in atmospheric river landfalls may exacerbate future snowpack decline in the Sierra Nevada. Such changes will have negative implications for water availability. The hypothesis also emphasizes the importance of maintaining and expanding hydroclimatic monitoring in mountain environments [5,20,71].

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Brief Communication: Early season snowpack loss and implications for over-snow vehicle recreation travel planning

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Abstract. Over-snow vehicle recreation contributes to rural economies but requires a minimum snow depth to mitigate negative impacts. Daily snow water equivalent (SWE) observations from weather stations in the Lake Tahoe region (western USA) and a SWE reanalysis product are used to estimate the onset dates of SWE corresponding to ~30 cm snow depth (SWE_{min}). Since 1985, median timing of SWE_{min} has increased by approximately two weeks. Potential proximal causes of this delay are investigated; rainfall is increasing during October-December with dry days also becoming more frequent. Adaptation strategies to address over-snow vehicle management challenges in recreation travel planning are explored.

1 Introduction

Ongoing and projected climate change is accelerating the decline of the cryosphere throughout Earth's mountain regions (Huss et al., 2017). Reductions in winter season snow, ice, and permafrost cover and volume primarily result from rising air temperatures (Brown and Mote, 2009) and shifts in precipitation from snow to rain (McCabe et al., 2018). These changes have cascading effects from mountains to lowlands with wide-ranging socioeconomic and ecologic impacts (Huss et al., 2017). In mountain regions of the United States, Europe, and Canada, winter recreation and tourism are central to economic activity. The economic benefits from winter recreation are projected to decline as a result of continued climate change that reduces season length and makes access to reliable snow more difficult (Wobus et al., 2017; Steiger et al., 2017).

Most winter tourism-based climate change impact studies have focused on ski resort-related activity (Steiger et al., 2017), although research has begun to address how other recreation-based components of the winter economy may be affected (e.g., Tercek and Rodman, 2016; Wobus et al., 2017). In the Lake Tahoe region of California (Figure 1a), and many other rural mountain areas of the western United States, over-snow vehicle (OSV) use is a regionally significant component of winter season recreation. Estimates of economic revenue from OSV recreation in the United States range between 7 and 26 billion USD (Fassnacht et al., 2018). As a result, OSV recreation has an appreciable economic impact on rural counties within the northern Sierra Nevada, many of which have a greater dependence on tourism-related employment than elsewhere in California (United States Census, 2013).

The proximity of the Lake Tahoe region to large population centres creates demand for OSV recreation over a limited and ecologically sensitive area. In order to limit potential negative impacts on natural resources (e.g., Keddy et al., 1979) during OSV operation, a minimum snow depth must be present. Minimum snow depth restrictions have been proposed by several forests undergoing winter travel management planning across the Sierra Nevada with a 30 cm recommended depth (United States Forest Service (USFS), 2013). Few forests have such a requirement at this time, but several are currently engaging in the process of winter travel management planning in response to a 2015 U.S. Federal Court ruling (Federal Register, 2015). The Eldorado National Forest in northern California (located in the southwestern quadrant of the study area) currently requires a minimum snow depth of approximately 30 cm for off-trail OSV use.

To our knowledge, no precise value of this minimum depth has been established through comprehensive studies quantifying OSV use and impacts or disturbance. Nonetheless, evidence indicates that OSV can alter the landscape when a shallow snowpack is present. Keddy et al. (1979) observed that OSV use on very shallow snow (10-20 cm deep) doubled snow density and compressed underlying vegetation. When OSV use began under a deeper snowpack, less difference in snow density and hardness was observed compared to a control (no-OSV use) snowpack (Fassnacht et al., 2018). Further complicating the minimum depth requirement is the dependence of snow depth on the density of the snow, which varies seasonally and as a function of weather conditions that drive snowpack metamorphism processes (Sturm et al., 2010).

Resource managers tasked with day-to-day operations such as opening and closing OSV trailheads over large, diverse areas may not have the resources to visit trailheads to obtain snow depth and density measurements. Instead, they often rely on subjectively-based qualitative assessments of what is deemed sufficient snow. Managers often do not set a specific OSV season, leaving it to user discretion to determine when OSV use is appropriate. This can potentially cause conflict with other uses during the start and end to the winter season and can allow opportunities for inadvertent damage to natural resources due to insufficient snow depth. Here, we estimate the median timing of achieving sufficient snow depths for OSV operation and their trends during the past 34 years using observations of snow water equivalent (SWE) and a reasonable assumption of snow density. The proximal causes of the identified increasingly later onset of achieving a minimum SWE value are further investigated. Because this trend towards later onset is not expected to reverse under continued regional warming, we provide adaptation strategies to cope with diminishing early season snowpack resources that can be included in forest travel management plans. The techniques can be extended to other regions where OSV recreation is an important component of economic activity and where early winter snowpack losses may be impacting winter recreation.

2 Data and Methods

The study area is the Lake Tahoe region of the western United States, a coastal, moderate elevation snow-dominated mountain range (Figure 1a). Daily maximum and minimum temperature, SWE, and precipitation were acquired for 16

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SNOTEL stations from the Natural Resource Conservation Service (http://www.nrcs.gov/snotel). Daily, gridded estimates of SWE at 100 m horizontal resolution were provided by a satellite-era SWE reanalysis product (Margulis et al., 2016). The period studied encompasses October 1 1984 to March 31 2018 (2016 for the SWE reanalysis), which corresponds to the winter seasons of 1985-2018.

No accepted value of a minimum snow depth exists for OSV operation. Anecdotal values used by managers vary between 150-450 mm depending on compaction (USFS, 2013), but these do not take into account variability in snow density. To provide a conservative and reasonable estimate of sufficient snow depth for what is assumed to be required for non-intrusive OSV operation, we specified 90 mm SWE (hereafter SWE_{min}) as the required depth for approval of OSV use. This value was obtained by equation (1):

$$SWE\ [mm] = d\ [mm] * {}^{\rho_s}/_{\rho_w}, \quad (1)$$

where d is depth, ρ_s is the density of the snow and ρ_w is the density of water. We assume that in a coastal snowpack with marginal compaction, ρ_s is typically 0.3 g/cm^3 (Sturm et al., 2010). This value appears reasonable to approximate a depth of 300 mm for early season conditions and is consistent with values used by the USFS (2013). Our SWE_{min} value is close to Patterson (2016) and Tercek and Rodman (2017), who both chose 100 mm SWE as a threshold value for winter recreation in the Rocky Mountain National Park and Yellowstone National Park, respectively. We report the median timing of when each SNOTEL station and reanalysis gridpoint achieves SWE_{min} and the annual timing as the median of the 16 SNOTEL stations.

To explore possible processes controlling the onset date of SWE_{min}, snow fractions (S_f) between October 1 and December 31 were calculated using the empirical hyperbolic tangent function formula developed by Dai (2008) with Sierra Nevada ecoregion parameter values estimated by Rajagopal and Harpold (2016). In contrast to Rajagopal and Harpold (2016), who used maximum temperature to estimate snow fraction, we selected average temperature because it gave a closer approximation to the mean snow level (~1,750 m) based upon independent estimates from observations (Hatchett et al., 2017). Dry days were days that zero precipitation was measured at the SNOTEL stations.

For all data, linear fits were estimated using a Theil-Sen slope and we report Spearman rank correlations. Statistical significance was tested using a modified Mann-Kendall test that accounts for serial correlation (see Hatchett et al., 2017 and references therein).

3 Results and Discussion

3.1 Timing of SWE_{min}

Median timing of achieving SWE_{min} ranged from early November to early January and was positively correlated with elevation (R^2=0.41, p<0.01; Figures 1a and 1b). For the selected SWE_{min}, nine of the 16 stations have significant (p<0.1) trends in towards later onset of SWE_{min} (Figure 1b). 13 of the 16 stations demonstrated a significant ($p<0.1$) trend when a value of SWE_{min} between 80 and 100 mm was chosen (Figure 1b). There was no relationship between trend in onset date and elevation, which suggests that regional weather variability is a first-order control on snowpack conditions. At the regional level, the median trend across all stations was 0.55 day year^{-1} ($p<0.001$; Figure 2a). This equates to SWE_{min} being achieved approximately 19 days later between the present day and the beginning of the record, although interannual variability still exists (Figure 2a). Results from the SWE reanalysis product are broadly consistent with the station-based analysis, indicating that timing of SWE_{min} is largely a function of elevation (Figure 1a). The median trend of the domain (approximately 15 days over the study period or 0.48 day year^{-1}) is close to the SNOTEL-based trend with the largest trends occurring above 2000 m (Figure 1c). The median trend of the domain when only considering statistically significant gridpoints ($p<0.05$) is approximately 21 days over the study period or 0.67 day year^{-1} (Figure 1d). The consistency of the results between the independent SNOTEL data and the SWE reanalysis product support the hypothesis that a delayed onset of SWE_{min} is occurring in the Lake Tahoe region. During years with later onset of SWE_{min} (such as 1991, 2012, or 2014; Figure 2a) most OSV users would likely opt out of recreating due to potential mechanical damage to OSVs. However, if sufficient snow existed above a certain elevation, inadvertent damage to the landscape could result when OSVs travel over shallow snowpacks in order to reach destinations with deeper snow. To ensure access to higher elevation areas for OSV use during poor lower elevation snowpack conditions, management plans could identify and implement corridors or rights-of-way that minimize landscape impacts while allowing access (Table 1).

3.2 Possible drivers of timing changes of SWE_{min}

The increasingly later onset of SWE_{min} (Figures 1c, 1d and 2a) is consistent with an observed increase (0.6 days yr^{-1}, $p<0.0001$) in the number of dry days during early winter (October-December; Figure 2b). The observed decreasing trend towards reduced early season snow fraction (S_f; 0.6% year^{-1}, $p<0.0001$; Figure 2c), implies that both increasing numbers of dry days and a shift towards increased rainfall are likely contributing to later onset of SWE_{min}. The reduction in precipitation falling as snow is primarily driven by warming temperatures (McCabe et al., 2018), which may be controlled by regional atmospheric and oceanic circulations that favour higher snow level storms (Hatchett et al., 2017). The higher snow levels (and hence lower S_f; Figures 2a-b) reduce snowpack accumulation during precipitation events and can allow for snowpack loss due to turbulent heat fluxes and heat input by rain. The more frequent dry conditions create more opportunities during which snowpack loss can occur via radiative and turbulent fluxes.

3.3 Implications for regional winter travel management planning

Due to its moderate elevation, the Lake Tahoe region is susceptible to climate change-induced warming (Walton et al., 2017). Our results provide another metric (later onset date of SWE_{min}) that is consistent with observations of ongoing changes in the Sierra Nevada cryosphere, including rising winter snow levels (Hatchett et al., 2017) and snowpack declines (Mote et al., 2018). Climate model projections for California support the continuation of these trends, with a drying and warming of the fall season (Swain et al., 2018) and an increased frequency of dry days (Polade et al., 2015). Projected snow-covered area declines are estimated to be the greatest during the beginning and end of the snow season (Walton et al., 2017). As a result, forest travel management plans should include adaptation strategies (Table 1) that can help managers and recreators cope with the increasing chances of a later opening date for OSV use but also provide flexibility in the event of an early, snowier-than-normal start to the winter. Flexible strategies developed by diverse stakeholder groups through public discourse are encouraged, as the continued reduction of area available for motorized and non-motorized users will lead to increasingly frequent use conflicts if not addressed.

Developing a suite of adaptive management strategies is essential if land managers are to meet legal obligations to manage OSV recreation in a manner that minimizes impacts to natural resources, wildlife, and conflict between uses (Federal Register, 2015). As snow seasons become more variable and less dependable overall, it will be necessary to utilize several complementary management strategies if land managers want to continue to provide high quality opportunities for all forms of winter recreation. For example, setting season dates that encompass the general times of the year when OSV use is appropriate, paired with a minimum SWE (or snow depth, depending on data availability), and allowing for OSV use on certain routes with a lower snowpack to provide access to higher-elevation areas may help to extend the OSV season. Likewise, it may be necessary to relocate winter trailheads to higher elevations as areas with consistent snowpack become shifted upwards in elevation. As the strategies in Table 1 show, however, there are tradeoffs with any strategy and OSV recreation is not the sole use of public lands in winter. Managing OSV recreation must occur in concert with managing other forms of winter recreation and protecting wildlife and natural resources (Federal Register, 2015). There is no one-size-fits-all strategy that will work for every national forest. It is essential that land managers work with public and agency stakeholders to craft locally-appropriate and equitable adaptation measures, taking into account potential impacts to and conflicts with other recreation uses, wildlife, natural resources, and other land management goals. It may also be necessary to accept that in the future, OSV and other forms of winter recreation (e.g., backcountry skiing and snowshoeing) will not be supported across all of the areas where it historically occurred. Winter travel planning is thus an excellent opportunity for land managers, particularly the United States Forest Service, to proactively address OSV management and consider how climate change is affecting OSV activities on national forests in order to maintain the opportunity for this form of winter recreation and its positive economic impact.

4 Concluding Remarks

Using snow water equivalent and a density assumption as a proxy for depth, we have presented a pilot study aimed at a better understanding of when the Lake Tahoe region attains sufficient snowpack depth to allow safe over-snow vehicle (OSV) usage. A station-based analysis of 16 remote weather stations in the region and a spatially distributed SWE reanalysis product indicated that the median timing of achieving sufficient depth varies with elevation from early November to late December. The median timing of sufficient depth has increased by approximately two weeks during the past three decades with significant changes on the order of three weeks. The proximal causes for this shift towards later onset appear to be due to both a shift from snowfall to rainfall and increases in dry day frequency during the early winter season. However, further research is needed to estimate specific contributions from each cause and constrain the role of surface-albedo (or other) feedbacks (Walton et al., 2017).

A primary limitation of our study is the lack of an established snow depth to avoid negative impacts of OSV operation as a function of land cover type and snow density. The work of Fassnacht et al. (2018) represents an important advance towards achieving this value, which can be used to guide winter travel management planning, although the United States Forest Service has begun to recommend a depth (USFS, 2013). Additional studies on achieving regionally-relevant minimum snow depths and better quantification of economic impacts from reduced snow cover area and duration will guide more robust travel management plans in national forests. They also can help prioritize pragmatic adaptation strategies for specific regions. Given the economic impact of OSV recreation and the likely reduction in land available for OSV or other human-powered recreation uses (Tercek and Rodman, 2016), combined with increasing numbers of winter recreation participants (Fassnacht et al., 2018), achieving winter travel management plans that are adaptive to varying snowpack conditions while minimizing user conflicts will be a key step towards sustainable mountain recreation.

Code Availability

The MATLAB code used for analysis is available upon request.

Data Availability

All data is publically available and has been properly cited in the text.

Competing Interests

HGE is employed by the Winter Wildlands Alliance (WWA). BJH has consulted for the WWA.

Author Contributions

BJH and HGE conceived and designed the study, interpreted the results, and wrote the paper. B.J.H. acquired data and performed the analysis.

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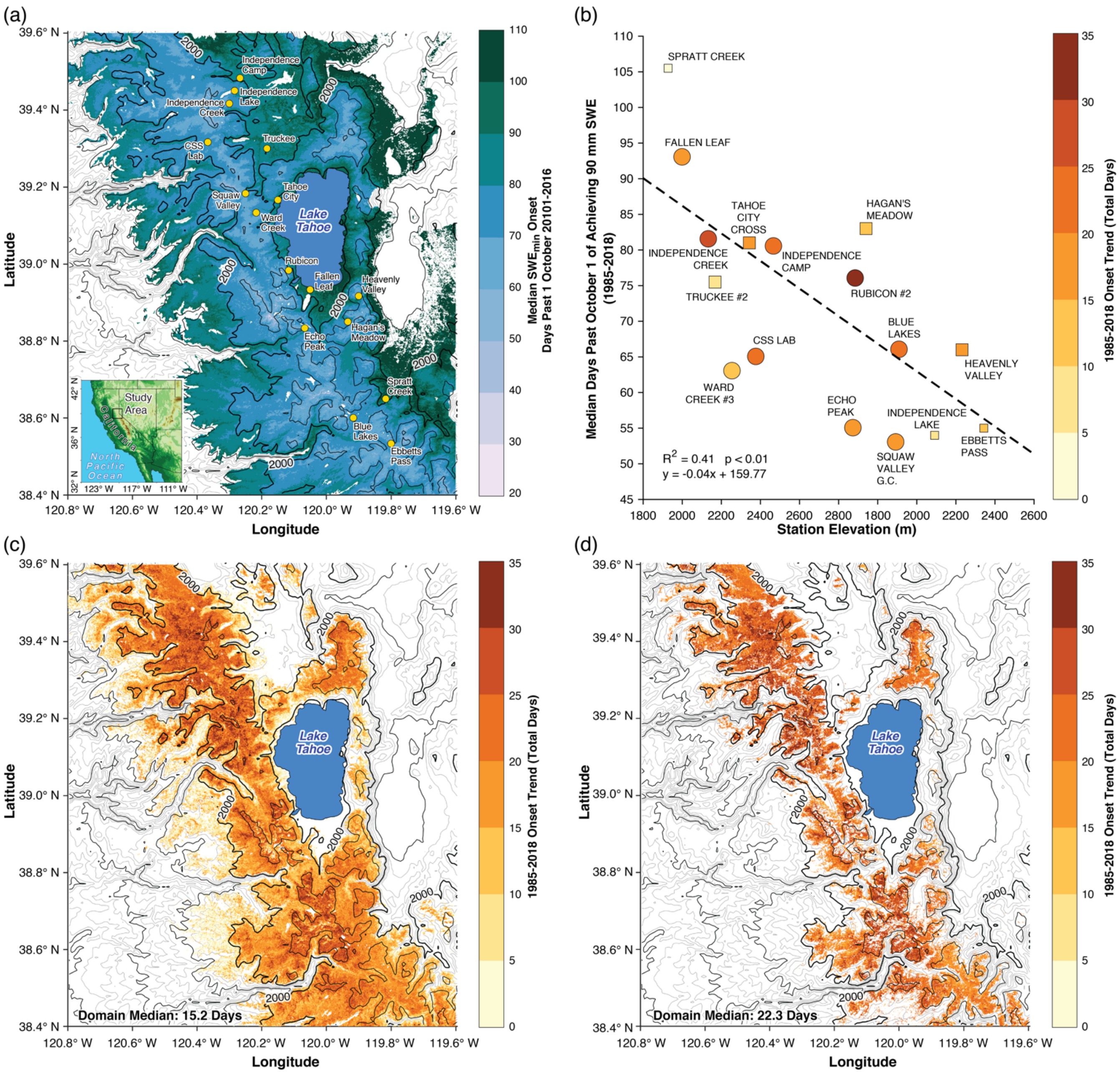

Figure 1: (a) Median 2001-2016 SWE_{min} (days past October 1) based on the SWE reanalysis product (Margulis et al., 2016) with SNOTEL stations shown as gold dots. The inset map shows the study area. (b) Timing of median SWE_{min} (days past October 1) by SNOTEL station elevation. Dots are colored by the trend (annual rate of snow depth timing change times 34 years). Dashed black line denotes the Theil-Sen linear fit. Large circles indicate significant trends (p<0.1) for SWE_{min}, while large squares indicate a significant (p<0.1) trend in SWE_{min} was identified for a value of SWE_{min} between 80 and 100 mm. Small squares indicate no significant trend. (c) Spatially distributed Theil-Sen linear trends in SWE_{min} over the period 1985-2016, calculated as the annual rate times the 32-year period. (d) As in (c) but showing only gridpoints with a statistically significant (p<0.05) trend in onset date. In panels a, c, and d, the thin (thick) grey contour lines indicate elevations every 125 m (500 m) while the thick black line indicates the 2000 m elevation contour (labeled). Gridpoints with more than three missing years were excluded from the analysis.

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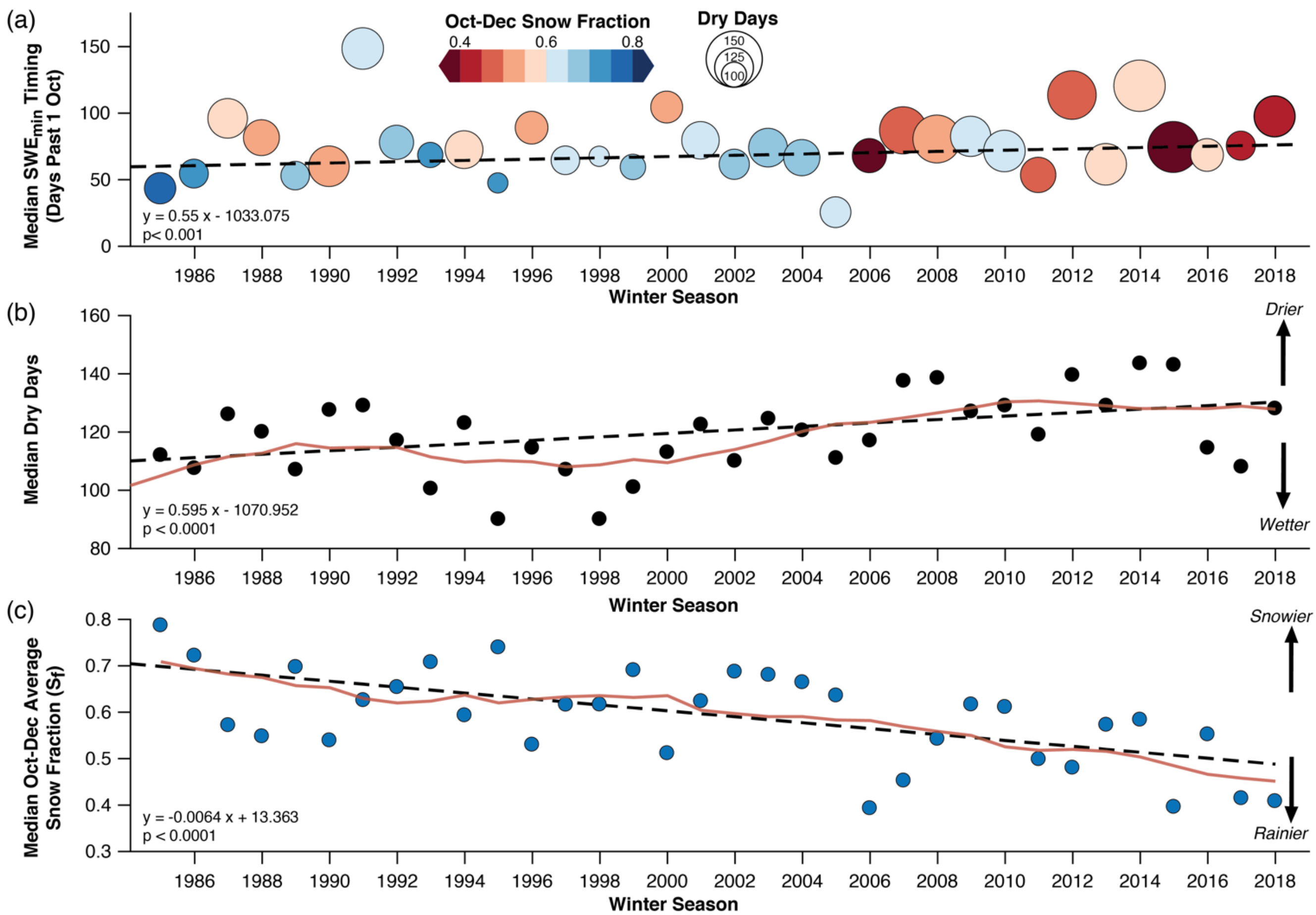

Figure 2: (a) Annual median timing of SWE_{min} (days past October 1) with dots colored by median Oct-Dec average snow fraction and sized according to the median number of Oct-Dec dry days. (b) Median early season (1 October-31 December) dry days. (c) As in (b) but for median snow fraction averaged over the 16 stations. In all figures, the dashed lines demonstrate Theil-Sen linear fits and red lines (b and c) show the five-year running mean.

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Adaptation Measure	**Benefit(s)**	**Challenge(s)**
Requirement of minimum snow depth off trail, but not on roads, or a lower minimum snow depth on roads	Allow OSV use even under extremely low snow conditions; grooming could be utilized to maximize snow depth on road	Preventing users from going off trail under low snow conditions; enforcement
Ensure high elevation access via a right-of-way	During warmer/drier years, snow conditions are likely to be better (deeper snowpack) at higher elevation	User group conflicts; presence of Wilderness at high elevation; impacts to snow-dependent wildlife species; demand; parking
Removal of blanket opening dates	Prevents opening before SWE_{min} achieved and will limit damage to landscape	Resources required to obtain snow condition information
Identify corridors that collect/retain more snow	During otherwise poor snow conditions, these areas may allow OSV recreation to occur, particularly at lower elevation areas	Need for data on these corridors
Trade-off: closure of low elevation/sensitive habitat for improved high elevation access	Eliminate chance of damaging landscapes in low elevation regions, increase in the number of days/year that OSV recreation can occur by enhanced high elevation access	Need for collaboration between stakeholders/user groups to identify areas where compromise could occur. May be opposed by those who must travel much further for OSV use.
Fee increases to enhance access and offset impacts from higher demand (i.e., restoration projects)	Would provide for additional resources to monitor trailhead conditions, improve parking/bathrooms at trailheads, fund restoration projects and creation of low-snow OSV trails	Fees are generally opposed by members of the public.

Table 1: Adaptation strategies to address loss of early winter snowpack for OSV recreation.

Evaluation of Observed and Simulated Snow Depths for Commencing Over Snow Vehicle Operation in the Sierra Nevada

Prepared for the *Winter Wildlands Alliance*
Benjamin Hatchett, Ph.D.

Draft Report Submitted: May 1, 2017
Revised Final Report Submitted: May 15, 2017

Executive Summary:

Over-snow vehicle (OSV) recreation represents a significant component of winter season recreation in the Sierra Nevada. In order to minimize negative impacts on natural resources such as vegetation damage and soil compaction during OSV operation, a minimum snow depth must be present, however to our knowledge no specific minimum value has been defined. Winter Wildlands Alliance suggests 46 cm (18 in) while some National Forest Special Orders require 30 cm (12 in). The minimum depth requirement is further complicated by the mechanical properties of snow that vary as a function of snow density. Nonetheless, resource managers tasked with opening and closing OSV trailheads over large spatial areas do not have the capability to visit each trailhead to obtain a snow depth measurement. Instead, they often must rely on remote measurements or historic opening dates. This study evaluates the use of station measurements and a process-based, semi-distributed snowpack model to inform OSV trailhead decision making. Using a conservative rule-of-thumb estimate of a minimum depth of 90 cm (12 in.) of compacted snow at a snow density of 0.3 g/cm^3, daily snow water equivalent measurements from 38 SNOwpack TELemetry (SNOTEL) weather stations are used to develop a relationship to determine when sufficient snow depths exist to open areas to OSV usage. Under an assumption of lower density snow (0.2 g/cm^3), the evaluated depth (45 cm) is consistent with the policy suggestion of Winter Wildlands Alliance (approximately 18 in). Output of snow depth anomalies (deviations from average conditions) from the SNOwpack Data ASsimilation (SNODAS) model is examined for the northern, central, and southern Sierra Nevada to demonstrate how this readily available model can be incorporated into decision making. Last, a protocol for citizen-science based depth measurements at OSV trailheads was developed for subsequent use that can provide additional data to complement SNOTEL and SNODAS estimates.

Analysis of SNOTEL data identified that median timing of achieving sufficient snow depths for OSV operation during the past 15 years (2003-2017) varied by elevation (R^2 = 0.39) from mid-October to late December. The long period of record (1981-2017) of SNOTEL stations enabled an analysis of long-term trends in opening dates. Since 1981, opening dates have increased at a rate of approximately 0.6 day per year, which today means that opening dates are nearly three weeks later. Linear relationships (0.25 > R^2 > 0.66) between snow depth and station elevation over four latitudinal bands were satisfactory to inform OSV opening decisions if station topographic settings (i.e., distance from the mountain crest) are considered. Incorporation of SNODAS output is recommended for decision making provided its limitations owing to uncertainty are appropriately factored into the decision process. A recently developed online tool, Google Climate Engine, that provides satellite-derived normalized differenced snow index is highlighted for additional guidance in identifying anomalous snow coverage conditions at the mountain range scale with high spatial resolution (500 m). To provide specific examples of the

types of weather conditions that lead to substantial snowpack losses after the depth requirement has been met, several specific case studies are summarized to highlight the types of weather conditions that lead to this scenario. The combined use of station and remotely-sensed data with model output is recommended for use in deciding when to open OSV trailheads.

Key Science Points:

1. Median dates of snow water equivalent (SWE) > 90 mm vary by elevation (R^2=0.39) from early November to late December.
2. Median dates of achieving SWE > 90 mm have increased by approximately 0.5 day per year over the past 37 years.
3. Timing of SWE > 90 mm varies by elevation with higher elevation sites achieving it earlier but with greater variance compared to lower elevation sites.

Unit Conversions: 25.4 mm (2.54 cm) = 1 in.; 1 m = 3.28 m

1. Introduction

Over snow vehicle (OSV) recreation represents a significant and growing component of winter season recreation in the mountains of California (Figure 1a) and throughout the western United States. With few exceptions, the annual increase in OSV registrations in California increased by 4-10% per year during the period from 1990-2008 (California Department of Parks and Recreation 2010). The proximity of the northern and central Sierra Nevada (Figure 1b) to large population centers such as the greater Sacramento and San Francisco metropolitan areas (Figure 1a) creates appreciable demand for OSV recreation in a relatively limited and ecologically sensitive area. In order to minimize negative impacts on natural resources such as vegetation damage (Stangl 1999) and soil compaction (Baker and Bithmann 2005) during OSV operation, a minimum snow depth must be present. To our knowledge, no precise value of this minimum depth has been produced via studies quantifying OSV use and disturbance. Further complicating the minimum depth requirement is the dependence of snow depth on the density of the snow, which varies seasonally and as a function of weather conditions. Newly fallen snow densities can vary from 0.05 g/cm^3 (typical interior western US powder snow) to 0.3 g/cm^3 (very wet coastal snow or compacted snow; Sturm et al. 2010). Although many national forests in California have a required minimum snow depth of 30 cm (12 in) for OSV use, not all forests have such a requirement (California Department of Parks and Recreation, 2010).

Resource managers tasked with opening and closing OSV trailheads over large spatial areas may not have the capability to visit each trailhead to obtain a snow depth measurement. Instead, they must rely on remote measurements or historic opening dates. This work aims to provide guidance to resource managers in using readily available snowpack data from weather stations (which may or may not provide depth measurements) and to highlight available online tools that can inform their decision making. Under a conservative snow density assumption (see Methods in section 3), we estimate the median timing of achieving sufficient snow depths for OSV operation and their trends through time. Relationships between timing of sufficient snow depth and elevation are examined. Several cases where snowpack losses during early winter are highlighted to provide resource managers with examples of the weather conditions at play in these events. This information may help increase situational awareness at times when trailheads may require closure to OSV use during the early season. Two web tools with map-based graphical user interfaces are provided with examples for how they can be applied to OSV trailhead decision making. A citizen science-based protocol for snow depth measurement was developed and can be implemented in subsequent winters. The results from this study can serve to facilitate continued research on snowpack trends during early season, the impact of these trends on winter recreation, and to facilitate improved resource management of areas where OSV is allowed.

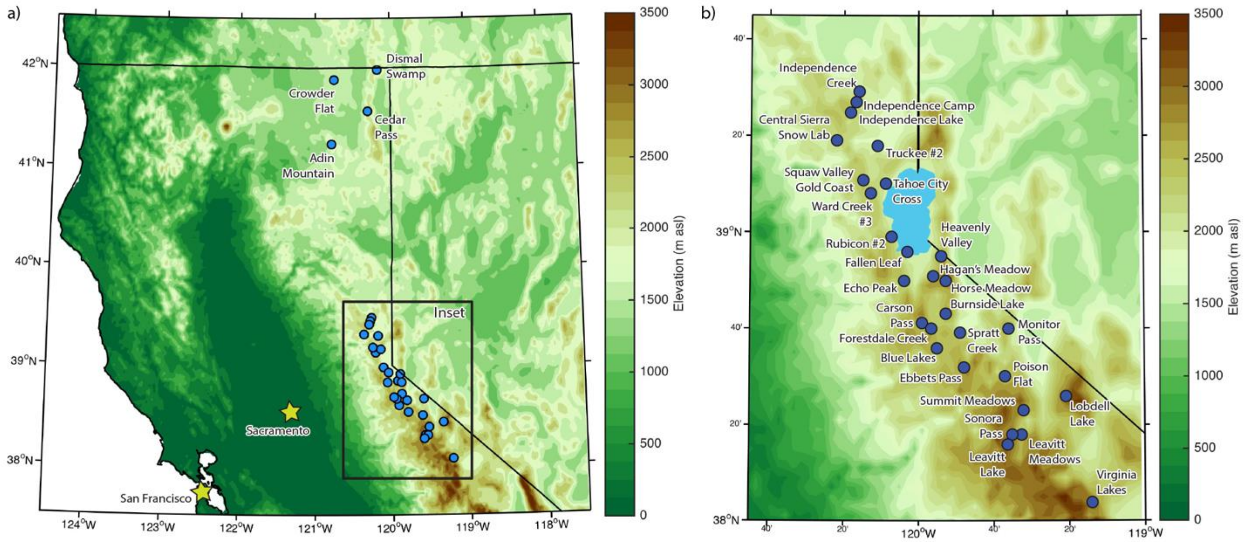

Figure 1: (a) Map of Sierra Nevada (and northern regions) with SNOTEL stations used in the analysis shown as blue dots. (b) Inset map showing stations in Lake Tahoe region of California. Elevations are shown as filled contours with 125 m intervals.

2. Data

Daily maximum temperature, minimum temperature, snow water equivalent, and precipitation from 38 SNOTEL stations spanning October 1 1980-February 28 2017 were acquired from the Natural Resource Conservation Service (http://www.nrcs.gov/snotel). Daily, gridded output at 25 km horizontal resolution of snow depth and snow water equivalent from the SNODAS model is available from October 1 2003-present. The data can be downloaded from the National Snow and Ice Data Center or accessed via a graphical user interface (GUI) at the National Operational Hydrologic Remote Sensing Center webpage (https://www.nohrsc.noaa.gov/interactive/html/map.html). The GUI allows the user to select the specific area, date, and variable of interest. SNODAS output was acquired for January 2012, January 2016, and March 2016. MODIS Aqua-derived normalized differenced snow index (NDSI) values at 500 m horizontal resolution are available between 1 October 2002-28 February 2017 and was acquired for January 2012, January 2016, and March 2016. The NDSI is created by differencing bands of remotely sensed reflectance in bands that snow reflects (0.66 mm) from the band that it does not reflect (1.6 mm) and dividing by the sum of the reflectance of these bands. NDSI was acquired from the Google Climate Engine GUI (www.climateengine.org; Huntington et al. 2017).

3. Methods

No established value exists for a minimum snow depth for OSV operation, but anecdotal values used by managers vary between 30-45 cm (12-18 in.) depending on compaction, which can be used as a surrogate for density. Such anecdotal values for minimum snow depth do not take into account variability in snow density. To provide a conservative estimate of sufficient snow depth for non-intrusive OSV operation, we specified 90 mm of snow water equivalent (SWE) at each SNOTEL station as the required depth for approval of OSV use. This value was obtained by the equation SWE [mm] = d [mm] * ρ_s / ρ_w and making the assumption that in a coastal snowpack with marginal compaction, ρ_s is typically 0.3 g/cm^3 (Sturm et al. 2010). Newly fallen snow varies from 0.05 g/cm^3 to 0.3 g/cm^3 with maximum densities observed during spring of 0.6 g/cm^3 (Sturm et al. 2010), therefore the chosen value appears reasonable to approximate a depth d of 300 mm (11.8 in.) for early-midwinter conditions in the Sierra Nevada. This depth value is consistent with values used by the United States Forest Service. The same SWE value under the assumption of less dense snow (0.2 g/cm^3) implies a depth of 45 cm, which is close to the depth recommended by the Wilderness Wildlands Alliance. Our SWE value is also close to that suggested by Patterson (2016), who chose 100 mm of SWE as a threshold value for winter recreation in the Rocky Mountain National Park of Colorado. Early in the season, low snow depths allow winter recreation to have the greatest effects on vegetation (Fox and Kiesse 2004). One would expect some degree of interannual and intraannual variability in snow density (in addition to snowfall and temperature regimes). Our approach can be considered conservative, as we use a density value on the upper end of the range of newly fallen snow and characteristic of midwinter, existing snow densities. This implies that more SWE is required to attain the depth threshold. As indicated above, using a lower density value would imply less SWE is required to achieve the minimum of 30 cm depth.

We take an exploratory approach towards examining the characteristics of early season snowpack development. Our study focuses on the northern and central Sierra Nevada (Figure 1b) but we also examined data from far northern California (Figure 1a). The region of focus (Figure 1b) has stations near 13 of the 19 California Sno-Parks, which are popular OSV staging areas (California Department of Parks and Recreation, 2010). Five of these Sno-Parks are in the Huntington Lake region near Fresno, California where no SNOTEL data is collected. We report the median timing of when each SNOTEL station achieves the minimum required 90 mm of SWE as a function of station elevation and latitude along with the variance. We also examined the frequency that stations would achieve 90 mm of SWE (thus allowing safe OSV operation) but then underwent a decline in SWE to less than 70 mm (the assumption being that OSV operation would no longer be recommended). Stations that underwent such a behavior two or more times and are located near popular OSV trailheads are noted. Examples are provided to demonstrate how warm and dry conditions as well as wet and warm conditions can produce SWE loss during early season and an example is provided to show rapid early melting at lower elevations. Climate normals, or average conditions, were calculated using the median of observed precipitation and SWE over the period 1981-2010 for each day of each year from October 1 to February 28 (where October 1, or the start of the water year, is taken as day 1). Unless otherwise specified, all years are expressed in terms of their respective water year that begins on October 1 *of the previous calendar year* and ends on September 30 of the calendar year of the water year. Least squares estimates were used to fit linear models to the data and the coefficient of determination (R^2 or the square of the correlation) as well as the linear regression equation are reported.

4. Results and Discussion

4.1 Trends in 90 mm SWE

Binning stations by elevation (low, middle, and high), the range of dates upon which 90 mm of SWE is achieved demonstrates substantial interannual variability (Figure 2). Median dates (black dots) of 90 mm SWE range from late January to early November with differences on the order of two to four weeks between individual years (Figure 2). Some years have small intra-station variability between 90 mm SWE dates (e.g., 2009 in Figure 2b) while others have larger intra-station variability (e.g., 2005 in Figure 2a). Long-term 37 year linear trends demonstrated substantial increases in the median date of 90 mm of SWE for all elevations with slopes on the order of 0.6 days yr^{-1} at middle and high elevations. Curiously, lower elevation stations had a slower rate of increased median opening date (0.3 days yr^{-1}). This finding is worthy of continued study as it may result from asymmetric rates of warming (greater rates at higher elevation compared to low elevation) or may imply that precipitation and temperature regimes during early season precipitation events are more strongly influencing middle and high elevation regions. Regardless of the causality of the warming, over 37 years, these rates equate OSV opening dates to be delayed nearly three weeks from historical assumptions developed over the past 20-40 years. For example, suppose a manager assumes that an OSV trailhead 'typically' opens in mid-November. Our findings suggest that during the past 10-15 years, this station may not actually achieve sufficient snow to open until early December. As a result, we only report the median opening dates for the past 15 years so that these dates are not biased towards the earlier opening dates of the 1980s and 1990s and are more representative of recent conditions. Low elevation (> 2146 m) stations typically open in late December with middle elevation (between 2146 m and 2520 m) and high elevation (> 2520 m) opening in early areas opening in early December.

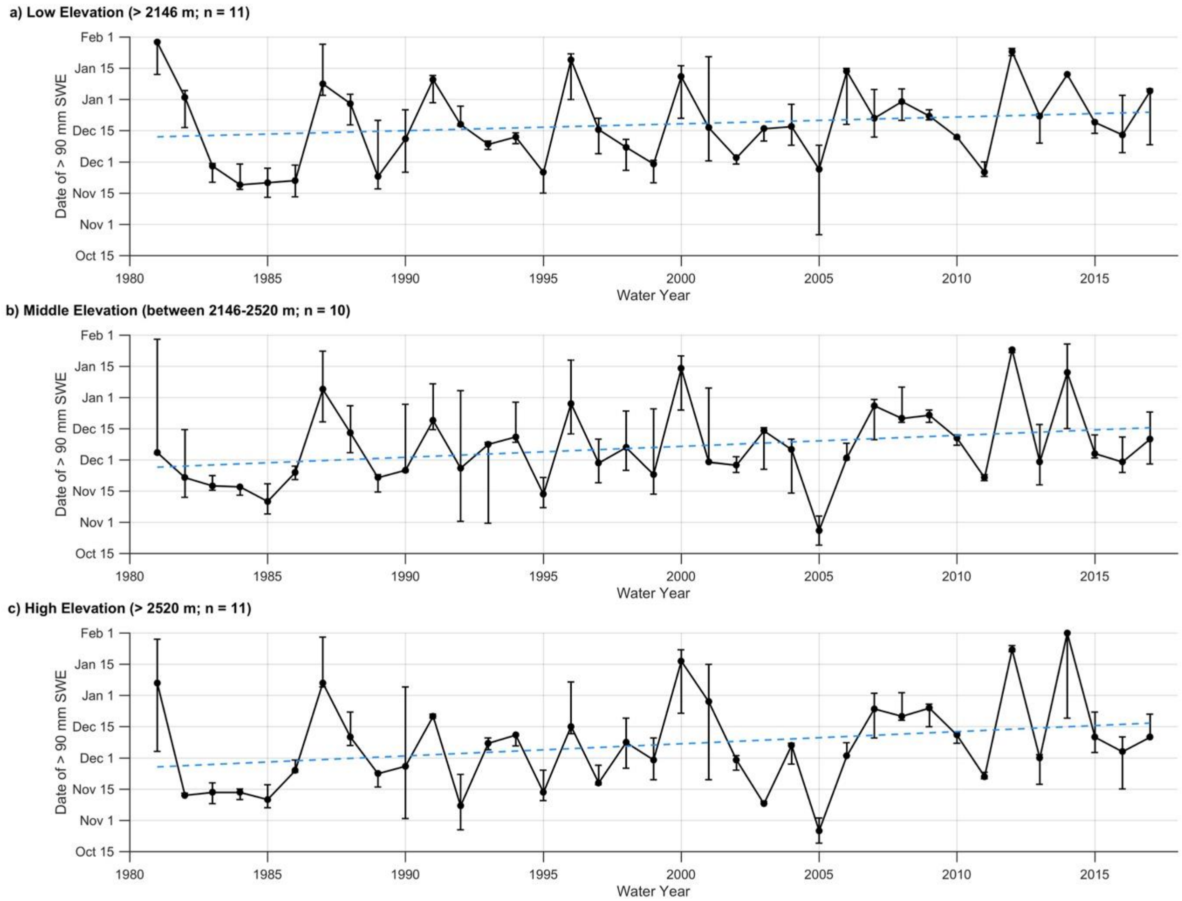

Figure 2: (a) Average median date of achieving >90 mm SWE (black line) with capped bars representing the upper and lower quartile. Dashed blue line represents the 37 year linear trends. (b) As in (a) but for middle elevation stations. (c) As in (a) but for high elevation stations. Note that substantially fewer stations existed at all elevations prior to 1990.

4.2 Median timing of achieving 90 mm SWE

Due to the identified trends towards later dates of achieving 90 mm SWE, we report the median timing of this date over the past 15 years (2003-2017). Middle to higher elevation sites typically achieve 90 mm of SWE during the month of November, with lower elevation sites taking until middle to late December (Figure 3). Please note that the x-axis is reversed in Figure 3 such that the earliest (latest) stations reaching 90 mm SWE are on the left (right). The role of latitude in typical OSV opening dates varies markedly. This results from the relationship being complicated by the southward increase in elevation of the Sierra Nevada that can offset the cooling experienced by more northerly latitudes during the transition into boreal winter. Section 4.3 addresses the latitude-specific relationships in more detail. The larger dot sizes in Figure 3 indicate greater variance in the timing of 90 mm SWE and tend to be concentrated in the higher elevations. This is due to interannual precipitation variability; some years have cold, wet fall seasons while other years are much drier or are characterized by warmer wet storms (such as in October 2009 and October 2016) where little precipitation falls as snow. The moderate positive correlation (R^2 = 0.39) at the mountain range scale indicates that elevation alone can be used as a first order measure to indicate the timing of OSV trailhead opening. Comparisons of historical opening dates as a function of elevation with the timing of 90 mm SWE at nearby stations would provide useful information regarding the use of elevation in determining trailhead opening timing.

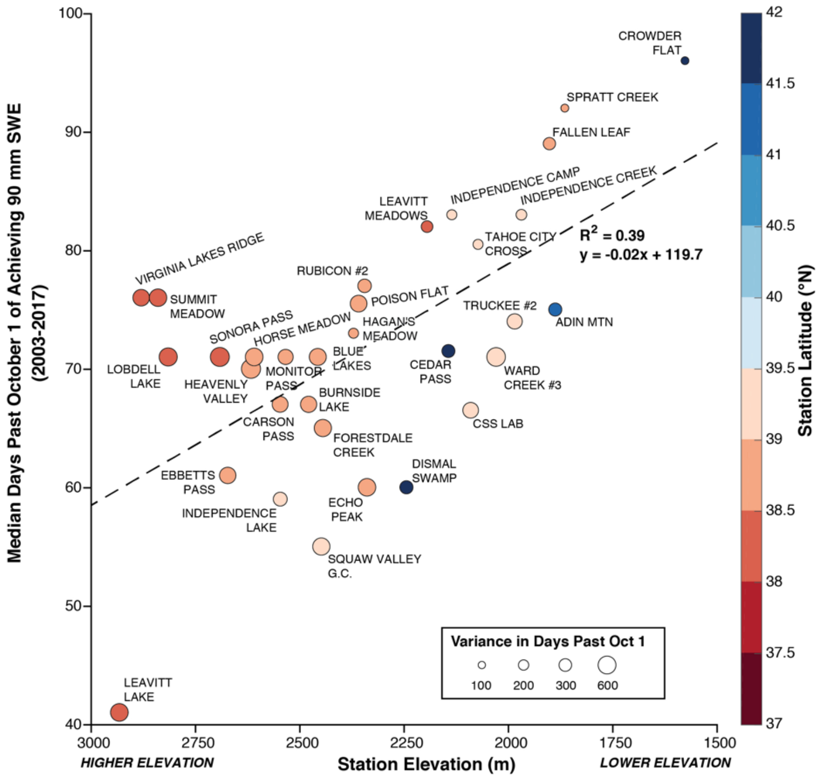

Figure 3: Timing of median opening date (>90 mm SWE; in days past October 1) of OSV usage by station elevation (y-axis) and latitude (filled contours). Dots are sized by the variance in days past October 1 of achieving 90 mm SWE. Dashed black line denotes the linear fit (R^2 = 0.39). Note the reversed direction of x-axis so that higher elevation stations are shown to reach satisfactory snow water equivalent earlier.

4.3 90 mm of SWE by station elevation, binned by latitude

Regardless of latitude, the increasing value of the slope coefficient in the slope equation (m in $y = mx + b$) with time for all locations (Figures 4-7) indicates the preferential increase in snow accumulation at higher elevation that builds throughout the winter season. At the highest latitudes of the study area, SWE as a function of station elevation is strongly correlated with elevation ($0.86 > R^2 > 0.96$) throughout the early portion of the winter (Figure 4). For the north Tahoe region (Figure 5), SWE is less well-explained by elevation but still moderately positively correlated ($0.51 > R^2 > 0.66$). Presumably this results from the variability of station locations with respect to the Sierra Nevada crest. A strong rain shadow effect results as orographic precipitation enhancement along the windward side depletes moisture and precipitation is inhibited by descending adiabatic motions as air parcels move downstream (to the east). This results in why stations near the crest, such as the Central Sierra Snow Lab (CSS Lab) or Squaw Valley Gold Coast have higher SWE values than the linear fit estimates while stations lying in the lee of the crest (Tahoe City Cross and Independence Camp) tend to have lower SWE values (Figure 5).

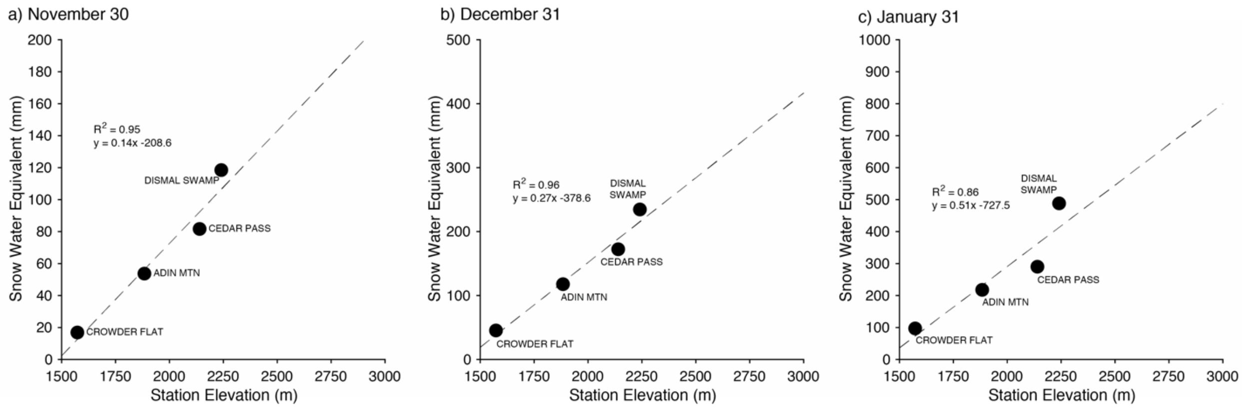

Figure 4: Relationship between station elevation and snow water equivalent for varying end-of-month dates: (a) November 30, (b) December 31, and (c) January 31 for far northern California (>40°N).

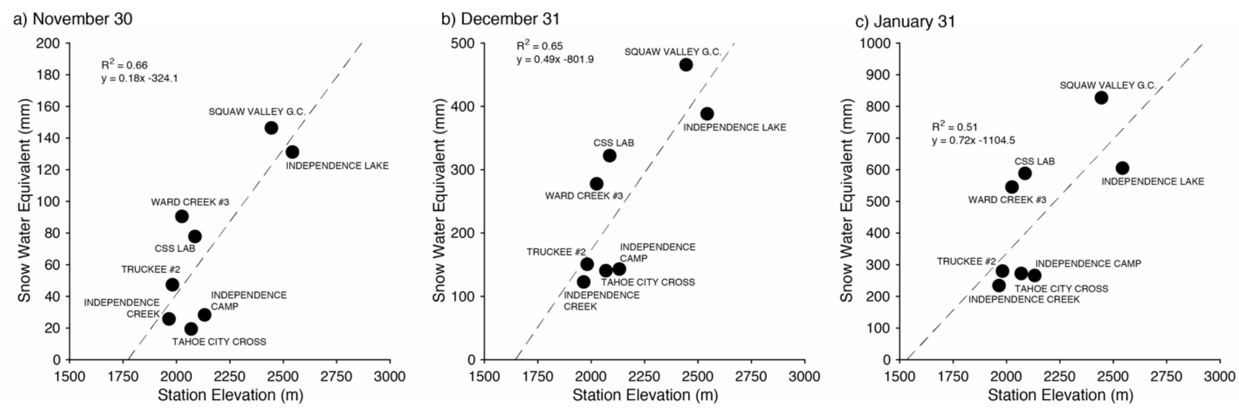

Figure 5: As in Figure 4, but for the north Tahoe region (39-40° N).

Moving further south into the south Tahoe region (Figure 6), increased spread of observed SWE as a function of station elevation is observed, leading to weaker correlations (0.36> R^2 > 0.41). The rain shadow effect may again be influencing the results in this case as Echo Peak sits along the crest while many of the other stations lie well to the east of the crest in the Carson Range (Figure 1). Regardless, the Fallen Leaf to Heavenly Valley relationship can serve as a first-order estimate of low to higher elevation SWE, especially if Carson Pass and Blue Lakes (OSV trailhead) are considered as well. Blue Lakes can be considered a maximum estimate of SWE (and depth) given that it tends to have more SWE than predicted by the linear model. The decrease in SWE dependence on elevation with decreasing latitude continues into the central Sierra (Figure 7) where relationships between SWE and elevation are moderately (at best) and positively correlated (0.25> R^2 > 0.31). Leavitt Lake is likely influenced by wind-driven gauge overcatch and thus should always be considered as a maximum bound on the possible SWE for its elevation; note how it plots far above the linear estimates regardless of date of year (Figure 7). Lobdell Lake and Virginia Lakes Ridge are located well east of the Sierra Nevada crest and thus tend to have less SWE for their elevation than the linear model predicts. Virginia Lakes is a major OSV access point with substantial sensitive riparian and aspen habitat in the area, and thus it is recommended to wait to allow OSV operation until the station reports 90 mm

SWE. This conservative approach may prevent damage to sensitive habitats. On the contrary, the use of Leavitt Lake as an indicator (which has virtually an identical elevation to Virginia Lakes Ridge) would likely promote damage via compaction or unintentional erosion as this station likely is reporting more snow than actually exists regionally.

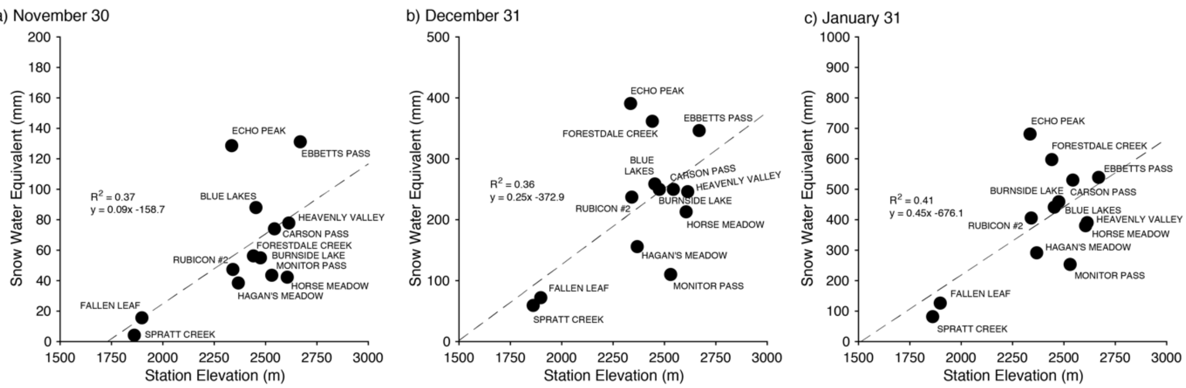

Figure 6: As in Figure 4, but for the south Tahoe region (38.5-39° N).

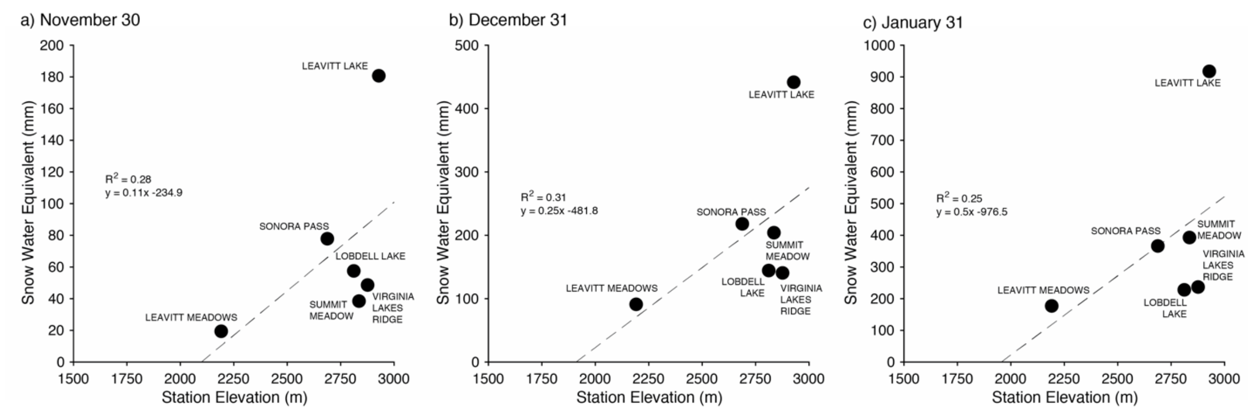

Figure 7: As in Figure 4, but for the central Sierra region (<38.5° N).

4.4 SWE loss once 90 mm has been achieved

A possible concern for OSV trailhead managers arises when sufficient snowpack develops to open the trailhead but is then followed by weather conditions that deplete the snowpack. Such depletion can put vegetation and soil at risk for disturbance during OSV operation. Figure 8 shows the number of times each station underwent a SWE reduction from 90 mm to below 70 mm during the period of study, plotted as a function of elevation. Stations with multiple SWE depletions near OSV trailheads are bolded. Large variability is observed in the number of SWE depletions as a function of elevation. Contrary to expectation, middle and upper elevation stations did exhibit multiple occurrences of SWE depletion. The most frequent depletions (two) for popular OSV destinations at high elevation occurred at Ebbetts Pass with Ward Creek and Leavitt Lake representing middle elevations. Very low elevation stations, as expected, showed the highest frequency of SWE depletion. Squaw Valley, the CSS Lab, and Echo Peak are all at middle elevations but located close to the Sierra Crest and may be some of the most susceptible to intense midwinter rain-on-snow events (Guan et al. 2016). The lack of SNOTEL stations west of the crest prohibited an analysis of lower elevation windward side evaluations. Snow pillow data is available for this region, but we were unable to download this data in an automated manner at this time. Continuing work seeks to acquire the windward side data in order to extend the analysis to this region.

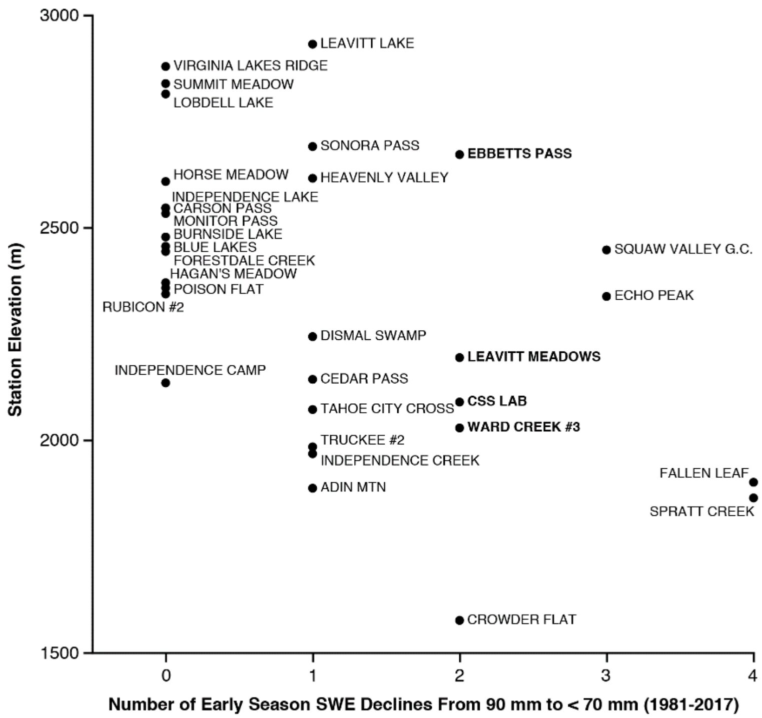

Figure 8: Number of occurrences for each station, by elevation, that SWE declined from 90 mm to below 70 mm before February 28 during the period from water years 1981-2017. Bolded stations are known to have nearby OSV trailheads and had multiple early SWE declines observed.

Three processes that can lead to SWE depletion are presented in Figures 9-11. Two of these examples are examined in a spatial manner in Figures 12c, 13, and 15. The first process is that of a wet snow drought (Hatchett and McEvoy, manuscript submitted to *Bulletin of the American Meteorological Society*) observed at Ward Creek (a popular OSV trailhead above the west shore of Lake Tahoe). A wet snow drought occurs when precipitation is above normal (note dashed gray line is well above the blue line in Figure 9a) but SWE is below normal (note thick dark green line is below the light thin green line in Figure 9a). Wet snow droughts are produced by warmer storms with higher elevation rainfall and exacerbated by above normal temperatures (occasional departures of maximum temperatures shown in Figure 9b). By late November, sufficient SWE existed to open the trailhead, however in early December a warm storm (note precipitation increase, SWE decrease, above normal maximum temperatures (note that maximum temperature controls precipitation phase at daily time steps; Rajagopal and Harpold (2016)) in Figure 9) caused SWE to decline below the 70 mm threshold (horizontal dashed black line in Figure 9a). Continued warmer storms with accumulating precipitation but falls in SWE combined with several above normal maximum temperatures led to the establishment of snow drought conditions for the remainder of December before a colder storm promoted substantial SWE accumulation on January 3 2017. This wet snow drought period coincided with the holiday period and likely intensive OSV use of the area and demonstrates an example of how closure of this trailhead may have been warranted in early December to prevent damage to the landscape. A view using SNODAS output of the evolution of this season is presented in section 4.6 (Figure 13).

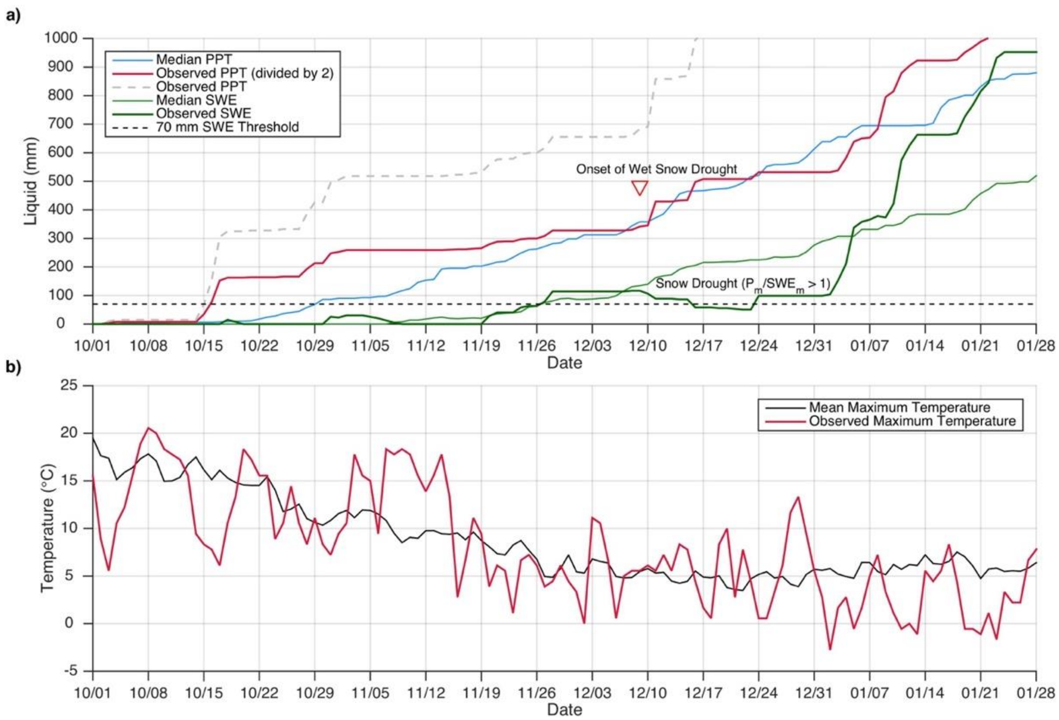

Figure 9: Example of SWE loss due to onset of wet and warm snow drought conditions at Ward Creek, California. (a) Observed precipitation shown in red but divided by two (dashed grey shows actual precipitation and the 1981-2010 median precipitation is shown in blue) and observed SWE in dark green (1981-2010 median SWE is shown by the thin green line). (b) Observed (red) and mean 1981-2010 maximum temperature.

A second SWE depletion example occurred at the Truckee station during a warm spell in early January of 1994. Below average SWE conditions existed throughout the December-February 1994 period, with SWE values hovering just below the 90 mm SWE threshold for several weeks in December until finally surpassing 90 mm on January 5 1994 (Figure 10a). Several days later, a period of persistent above average temperatures ("warm spell" on Figure 10b) coincided with a weak precipitation event (rain) that led to SWE depletion during the second and third weeks of January (Figure 10a). SWE did not decline continuously during this period, rather it reached a steady-state minimum but did not recover until early February. The relative flatness of the observed precipitation (red line in Figure 10a) indicates the multiple extended dry periods during the peak of winter. The combination of above average temperature with likely clear sky conditions (deduced from the lack of precipitation) implies that the Truckee observations represent a minimum SWE loss, as much greater losses would have resulted on sun exposed slopes due to radiation and above normal daytime temperatures. Lower elevation regions likely also lost appreciable snow due to the thermal regime.

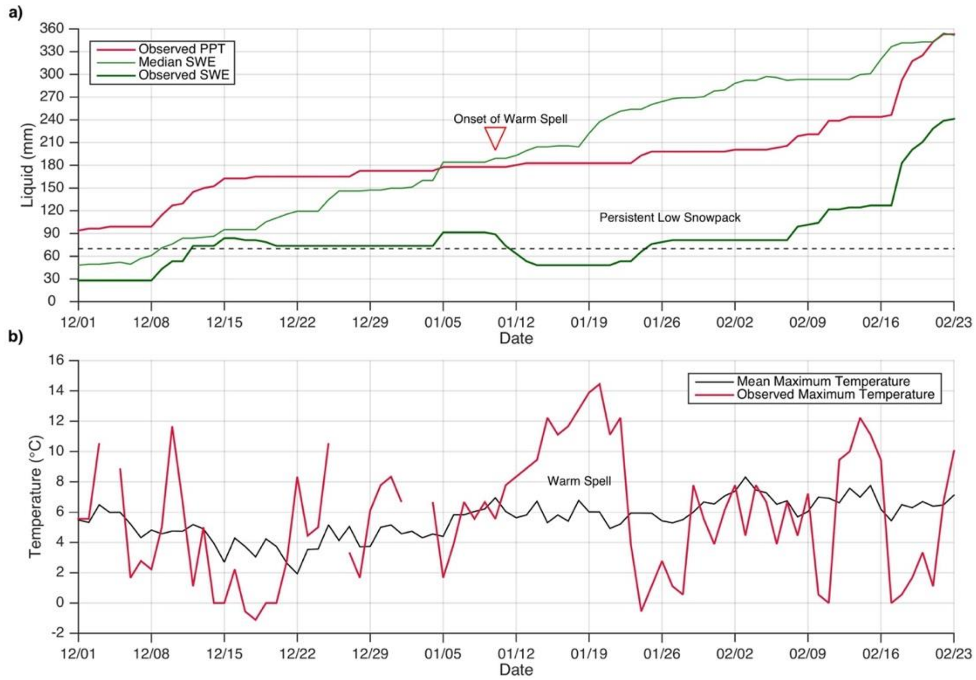

Figure 10: Example of SWE loss due to January warm spell Truckee, California. (a) Observed precipitation shown in red and observed SWE shown in dark green (1981-2010 median SWE is shown by the thin green line). (b) Observed (red) and mean 1981-2010 maximum temperature.

A final example of SWE depletion is provided in Figure 11 for the Tahoe City Cross SNOTEL station during the 2016 season. In this case, the purpose of this example is to demonstrate that rapid SWE loss can occur during late winter/early spring and result in poor OSV trailhead conditions at lower elevation areas. Throughout much of the year, both SWE (green line) and accumulated precipitation (dashed gold line) were well above normal (Figure 11). In mid-February (~day 120), SWE plummeted below normal and reached a value of 30 mm at the time of year (early March) when it normally achieves its maximum value. Persistent warm and dry conditions (note flat lines in accumulated precipitation that indicate periods of now precipitation in Figure 11) rapidly melted the snowpack during this time. This produced late onset snow drought conditions, where late in the season, accumulated precipitation is above average but SWE is below average due to early melting. Marginal recovery occurred during two storms in early and mid-March, but SWE quickly fell to 0 mm by the end of the month when normally 240 mm of SWE would be expected at this station. A spatial view of this example is provided using SNODAS output in section 4.6 (Figure 12c) and using Google Climate Engine remotely sensed observations in section 4.7 (Figure 15). This example demonstrates that OSV trailhead managers must remain vigilant throughout the season and continuously monitor weather and snowpack elevations at various elevations. Low elevation trailheads would likely have necessitated closures to protect natural resources during this period.

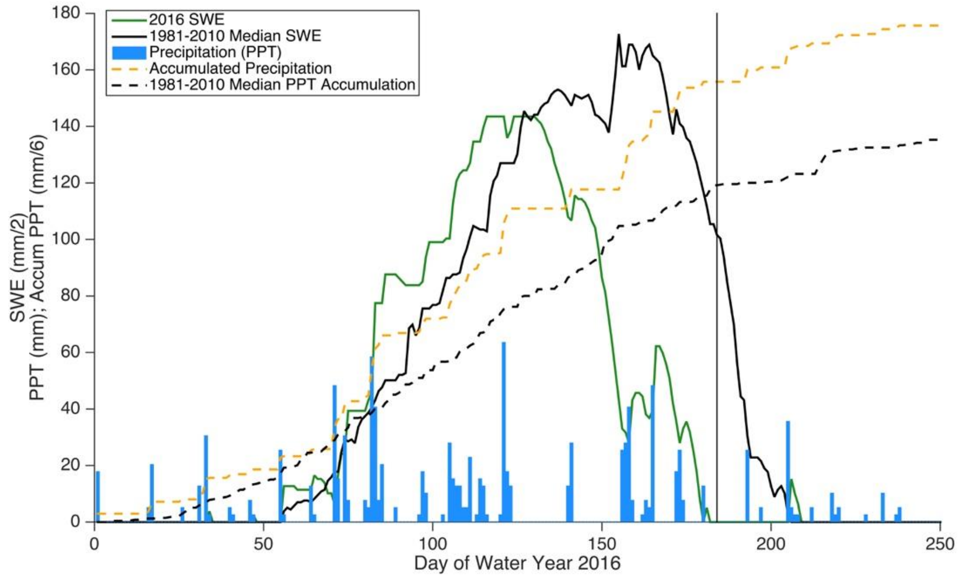

Figure 11: The spring loss of SWE at Tahoe City during 2016, indicative of the onset of late season snow drought. The black vertical line indicates April 1 2016 and the first day of the water year is October 1 2015.

4.5 SNODAS

Spatially distributed (1 km horizontal resolution) output from the process-based SNODAS model is available at daily resolution for much of North America and can be readily accessed online and manipulated to specific areas and output variables via the website listed in Section 2. The snow depth anomaly maps (Figures 12 and 13) are calculated by taking the snow depth output for a selected date and differencing these depths from the long-term (2003-2016) average, and may represent a useful tool for OSV trailhead managers. Figure 12 presents three examples of how SNODAS can be used to evaluate various scales of anomalous snow depths across the Sierra Nevada. Figure 13 shows the temporal evolution of how snow conditions changed over a one-month period in the Sierraville/Sierra City region.

Widespread dry snow drought conditions (well-below average precipitation and SWE; Hatchett and McEvoy, submitted) existed throughout the northern California region in January 2012 (Figure 12a). The greatest negative anomalies in snow depth (below average depths on the order of more than 24 in.) are found in the higher elevation regions of the Sierra Nevada. These findings are in agreement with satellite-based estimates of negative snow cover anomalies (Figure 14). During January of 2016, SNODAS demonstrates a strong depth anomaly gradient between the central and southern Sierra Nevada with positive anomalies to the north and negative anomalies to the south (Figure 12b). Interestingly, lower elevations have positive anomalies throughout while the High Sierra region exhibits below average depths. This may result from several possible combinations of weather conditions: 1) colder, dry storms with weaker orographic precipitation gradients that result in more snow (relative to average conditions) at lower elevations with less snow at higher elevations, 2) wind transport and 3) sublimation that can remove snow preferentially from higher elevations. Range-wide conditions following the late-season onset of snow drought (recall Section 4.4 and Figure 11) shows the continuation of the north-south gradient in snow depth anomalies (cf. Figure 13b and 13c). Figure 13c also demonstrates the low elevation anomalies throughout the Sierra Nevada that resulted from the dry and warm conditions during February. These below average snow depth conditions were particularly extensive along the eastern (leeward) side of the Sierra Nevada.

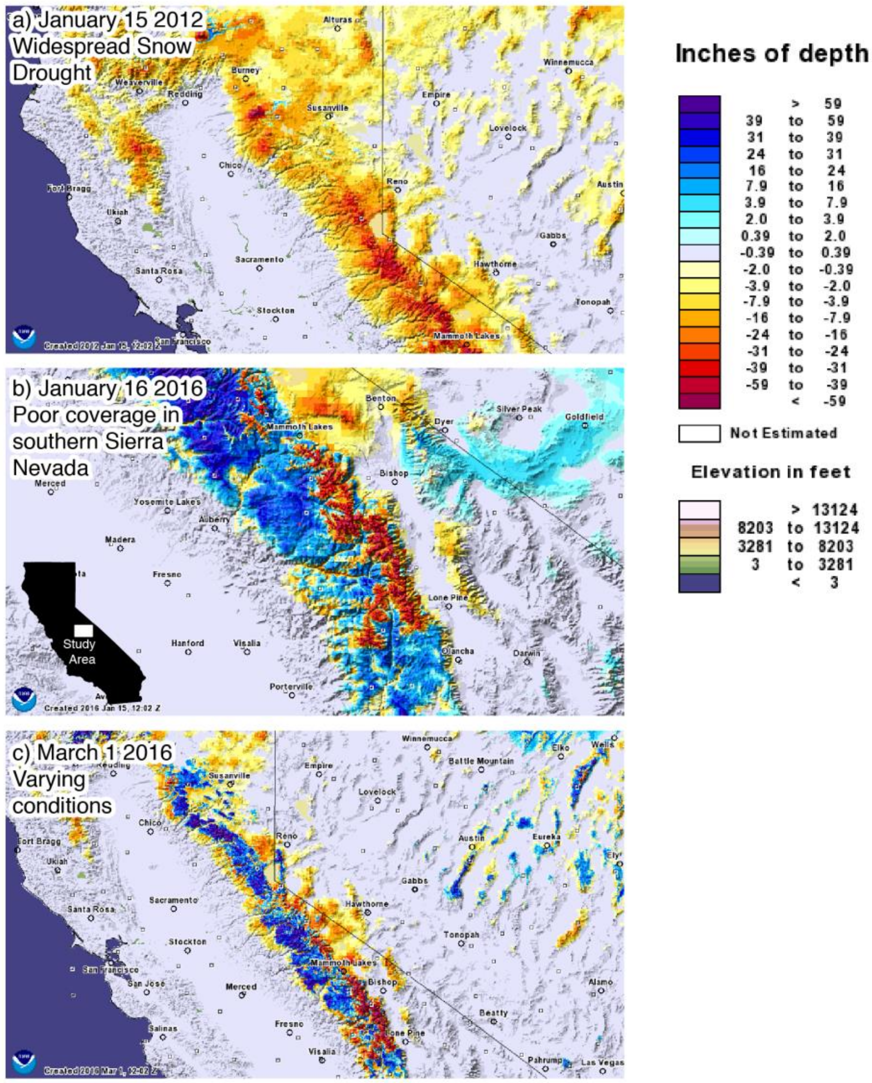

Figure 12: Examples of SNODAS snow depth anomalies (observed minus 2003-2016 averages) at various scales. (a) Northern California, (b) southern Sierra Nevada, and (c) near-entirety of the Sierra Nevada.

The relatively fine scale horizontal resolution (1 km) of SNODAS allows detailed examinations of complex terrain. During the wet snow drought period of December 2016-January 2017 (described in Section 4.4), the lower elevation northern Sierra Nevada underwent a dramatic transition from below average snow depths at most elevations in mid-December (Figure 13a) to marginal recovery in late December (Figure 13b) to being well-above normal in early January throughout the domain (Figure 13c). The precipitation events producing the recovery and towards plentiful (>40 in. anomalous depth) snow conditions are shown in Figure 9a. During December, Figures 13a-b indicate that many populated regions were 6 in. to more than 10 in. below average in terms of snow depth. If one assumes that such low elevation regions are likely near their climatological median (mid-December, cf. Figures 2a, 3, and 5a-b) for sufficient snow depth (11 in.) under the SWE approximation, the SNODAS output suggests that widespread areas likely do not have enough snow for safe OSV operation. If OSV trailheads exist near areas of anomalous positive snow depths (Figure 13a), a manager would be able to make a more informed decision about keeping these trailheads open (e.g., northwest of Truckee; Figure 13a) while closing those elsewhere (e.g., north of Sierra City near Graeagle or southeast of Sierraville; Figure 13a). After a storm, SNODAS can aid in reassessment of closures and openings (e.g., opening Sierra City area trailheads but keeping the region southeast of Sierraville closed; Figure 13b). As I am not sure about whether OSV trailheads can actually undergo opening and closing throughout the season, these ideas are merely speculation as to potential management decisions. In such events, field visits to ground truth the SNODAS output at anomalous positive depth areas is recommended if resources allow.

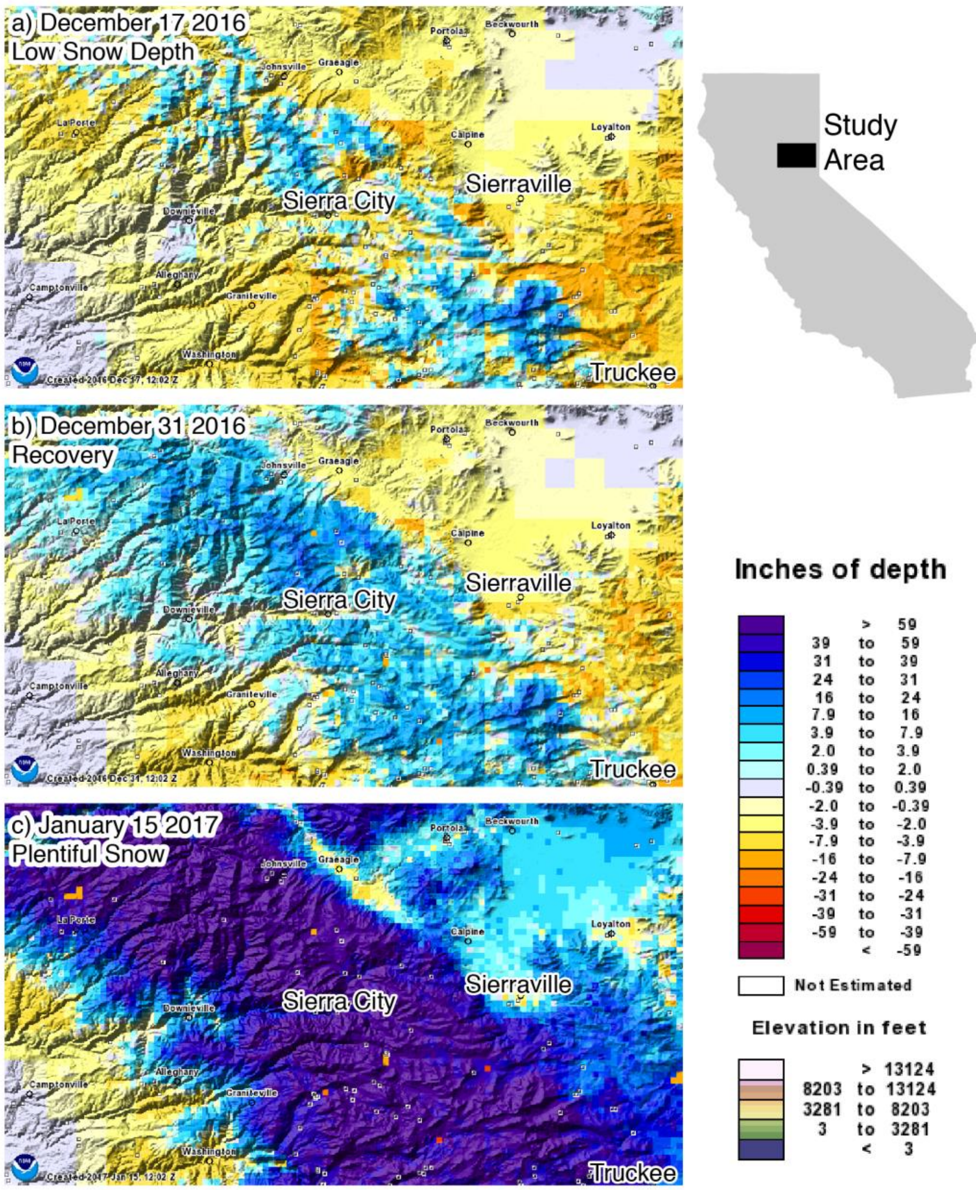

Figure 13: Evolution of the 2017 season in the northern Sierra Nevada through the snow depth anomaly (observed minus 2003-2016 averages) for (a) December 17 2016, (b) December 31 2016, and (c) January 15 2017.

The information provided by SNODAS will become substantially more useful once the citizen-science snow depth measuring program (with a protocol given in Appendix 1) has been implemented for several years. This project will provide independent depth information for specific areas of interest (OSV trailheads). Without independent depth measurements at the points of interest to compare against SNODAS output, little conclusive information or a robust empirical-statistical relationship can be developed between OSV trailheads and SNODAS estimates of snow depth. The acquisition of actual measurements will allow an estimation of SNODAS bias (too much or too little depth) for various times of the season and for various snow accumulation scenarios. This information will be useful in further constraining SNODAS estimates for OSV decision making and in providing feedback to the model development team in an effort to improve the model. Even more simply, such measurements will allow for a binary comparison to be made (presence/absence of snow). As it is a model that assimilates observed data, we can expect the uncertainty of SNODAS estimates to be larger in areas where few observations exist. In data-sparse regions and when field visits are not possible, SNODAS outputs of snow depth are recommended to be incorporated into OSV opening decision making provided that it is acknowledged that SNODAS likely represents a maximum estimate or upper bound of snow depth. A similar acknowledgement is nonetheless recommended in relatively data-rich regions such as the central and northern Sierra Nevada. Last, identification of below average snow depth conditions during the latter portions of winter seasons (e.g., Figure 12c) could be used to target regions for field studies to examine if damage to vegetation or soil compaction occurred under the shallow snow conditions with likely saturated soils.

4.6 Climate Engine

Google Climate Engine is a newly available web-based portal for accessing and visualizing climate and remote sensing data (climengine.appspot.com; Huntington et al. 2017). A screenshot of normalized differenced snow index (NDSI), or a satellite-based reflectance estimate of snow cover, for the period of early January 2012 (recall Figure 12a) is shown in Figure 14. The interface is user-friendly and offers a variety of calculations and the ability to download a geoTiff image file for use in ArcGIS or other analysis programs. Note the widespread negative values throughout California and Nevada indicating well-below average snow cover. While NDSI does not directly measure snow depth, its coverage is global, it is updated daily, and it has a horizontal grid resolution of 500 m. This allows it to be used to subjectively evaluate snow conditions (presence or absence and even degree of coverage) in remote regions that may not have data otherwise available. An example of this is provided in Figure 15, where low elevations around the Tahoe Basin underwent rapid snowmelt during a hot period in February 2016. Conditions at lower elevations rapidly deteriorated from above normal (Figure 15a) to below normal (Figure 15b), and observation stations tend to be sparse at these elevations. This situation could have severe negative impacts on OSV trailheads as users are still excited to ride but shallow conditions and saturated soils set up a favorable environment for compaction and disturbance. In this case, the Tahoe City Cross SNOTEL (Figure 16) did capture the melt out, but this may not be the case for other regions of the Sierra Nevada or elsewhere in the intermountain west. For these regions, Climate Engine can be used in conjunction with SNODAS to provide information on likely OSV trailhead snow depths (cf. Figure 13b and 13c). For example, if NDSI anomaly values are strongly negative and SNODAS also shows negative snow depth anomalies (cf. Figure 13b and Figure 15b, it would provide confidence in the decision to limit OSV access at certain trailheads. On the other hand, if NDSI and SNODAS do not agree, the manager may want to inquire with locals or perform a field visit if possible. Either way, the combined use of these two web-based tools can aid in OSV trailhead decision making by providing additional guidance on the spatial distribution of anomalous positive (more) or negative (less) snow depths in their management areas. Furthermore, use of these tools in decision making allows the manager to provide evidence in support of their decision that can be communicated to the public via social media channels or on the web. A dialogue based upon data represents a better outcome than one that does not exist or rests solely upon what appears to be the opinion of a government official.

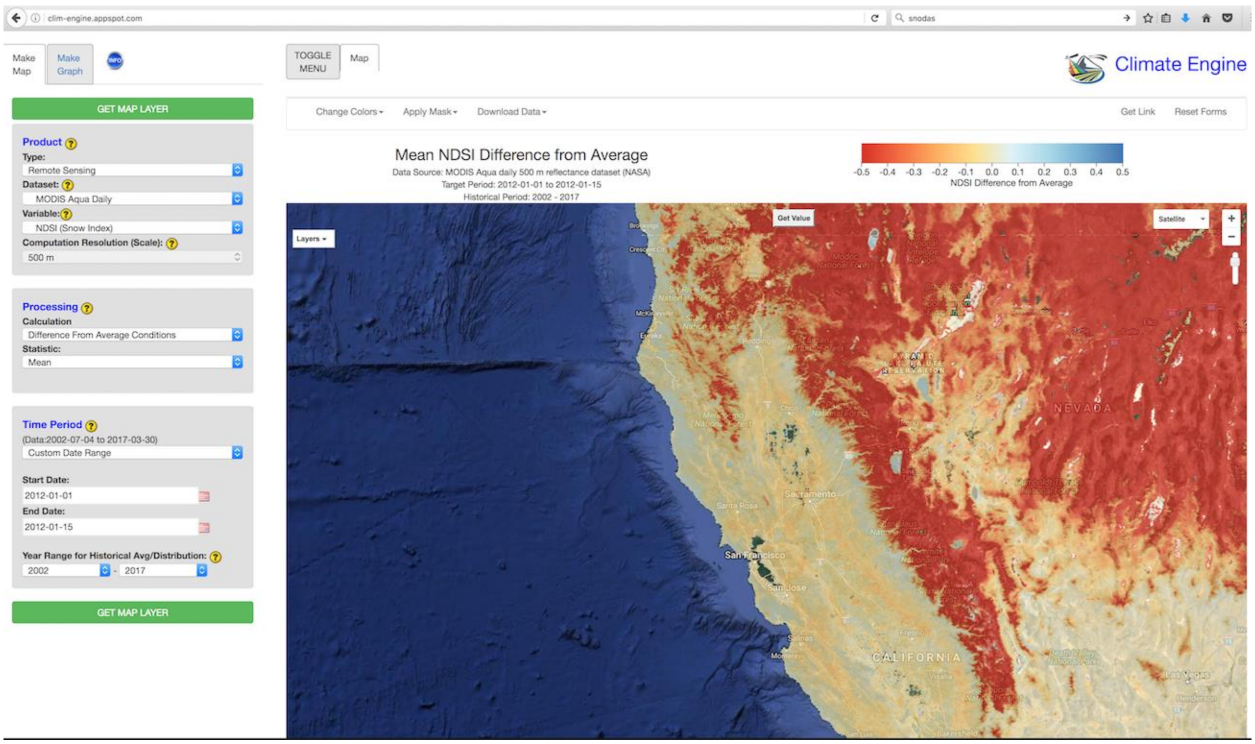

Figure 14: Screenshot example of the Google Climate Engine interface during the January 2012 low snow conditions (cf. Figure 12a).

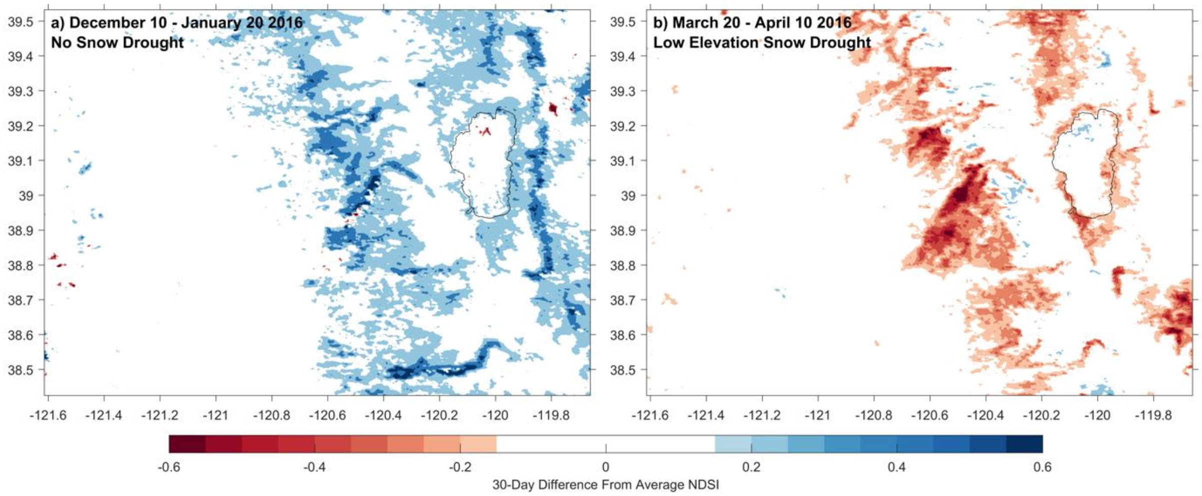

Figure 15: Onset of lower elevation snow drought in the Lake Tahoe region was determined by MODIS Aqua normalized differenced snow index anomalies (observed minus 2002-2017 average). (a) Anomalous positive NDSI (blue colors) during December-January resulted from above normal precipitation and snowfall at lower elevations. (b) Persistent warm and dry conditions during February (see also Figure 14) resulted in substantial snowpack decline at lower elevations and created negative NDSI (red colors) along the periphery of the Sierra Nevada. This would indicate that while sufficient snowpack exists at upper elevations for OSV usage, lower elevation trailheads may have become susceptible to disturbance.

5. Summary and Future Work

We have presented a pilot study focused on developing a better understanding of when specific locations attain sufficient snowpack conditions to allow safe over snow vehicle (OSV) usage. A station-based observational analysis of 38 remote snow sensors in the Sierra Nevada indicated median timing of achieving sufficient depth under a density assumption to allow OSV usage ranged from mid-October-late December as a function of elevation. Our analysis indicates that the median timing for opening trailheads for OSV operation increased by nearly three weeks during the past 37 years. Online snowpack models such as SNODAS and satellite-based data hosted and visualized through Google Climate Engine were shown to provide additional guidance in OSV trailhead opening decision making. Three types of weather regimes that can lead to snowpack decreases during the winter or early low elevation melt-out were demonstrated. Employing the citizen science-based protocol (see Appendix 1) during the early portion of subsequent winters will allow additional verification of the findings described herein as well as adjusting them as necessary to better inform decision makers on the timing of OSV trailhead opening.

Even simplistic predictive models of snow accumulation driven by inputs of precipitation and temperature at a point in space but distributed in time are not trivial to implement. The readily available output from SNODAS represents a physically realistic and reasonable method to estimate spatially distributed snowpack conditions (i.e., depth and SWE) given the knowledge that SNODAS represents a maximum estimate. Short of field visits and until several years of trailhead snow depth measurements have been performed, this study recommends the combined use of SNODAS with station data (if available and recognizing that SNODAS assimilates this data) and NDSI from Google Climate Engine to inform OSV trailhead opening decision making. For OSV trailhead locations with nearby snow sensors, the simple, derived relationships explaining snow depth as a function of elevation (under the assumption of maritime snow density) are recommended when making trailhead opening decisions. In these regions, use of SNODAS and NDSI are still recommended. The continued implementation of the citizen science snow depth protocol is strongly encouraged in order to better constrain estimates of snow depth from observations and model output. A final recommendation is to perform a detailed evaluation of soil compaction effects of OSV usage under varying snow depth, snow density, and soil conditions. Such a study could be undertaken during the early winter season using a soil cone penetrometer, several snowmachines of varying characteristics, a snow density measurement kit, and a soil tamper. The results of this study would help quantify the minimum snow depth (under varying densities) required to avoid soil compaction from OSV use and could guide more robust travel management plans in National Forests.

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Appendix I: Snow Sampling Protocol

Available online at: [https://docs.google.com/document/d/1DTdkW7vJKchhpfMLFWUaGb_4w4kHFl86TaedLR2_G2k/edit]

Measuring snow depth at OSV trailheads

Primary goal: To develop a relationship between measured depth at a trailhead location and observed snow water equivalent (SWE) and/or depth from nearby snow pillows from the SNOwpack TELemetry (SNOTEL) or California Department of Water Resources stations and using the distributed SNOw Data ASsimilation (SNODAS) model. Doing so will improve the USFS' knowledge of when sufficient snow depth exists at Over Snow Vehicle (OSV) trailheads to open or close them.

Materials Required:

1. Probe with increments in centimeters (preferably) or inches.
2. Camera (a phone with a panorama camera function is ideal)
3. Rite in the Rain notebook or Mountain Hub App
4. Phone with Mountain Hub App (MHApp) installed (David Page will be able to help you set this up).

Steps in Measuring Depth:

1. Identify the trailhead location you would like to sample (e.g., Mount Rose Meadows, Yuba Pass, etc.) and travel to this area.
2. The MHApp will record details about the trailhead including: latitude and longitude, elevation, date and time of sampling, but feel free to note weather conditions (snowing, sunny), and any other relevant information ('very patchy snow cover', 'trailhead is a USFS road', etc.) using the MHApp. Alternatively, if you do not have a smartphone, record this information in your notebook and email it to a friend who has a smartphone with the MHApp when you get home. They will probably trade data entry for a favorite beverage or two.
3. From the parking area, use your camera to photograph a complete view of the trailhead. This can be done through incremental photographs along a constant horizon or best done using the panorama function on your phone's camera. If the trailhead is a road, this can be done with a single photo, but in the case of a trailhead like Mount Rose, a 180° panorama will be excellent. This step will provide useful information on the context of the trailhead in terms of topography, vegetation, and variability of snow coverage, how the area is used to stage OSVs, how the OSV traffic behaves at the trailhead (a few tracks confined to a road/trail or driving all over the place) among other things.
4. Note also the snow conditions, being as descriptive as necessary. This can range from 'uniform, consolidated, compacted, spring snow' to 'highly variable winter snow, ranging from untracked and still fresh to greatly compacted'. In the case of the latter, you can estimate the fraction of each (20% fresh, 50% compacted, 30% very compacted).
5. Identify and note the primary corridor, if one exists, of OSV usage/staging. This will be the area you want to sample. Make sure this area is captured in your study area photo in step 3. If you would like, take a screenshot of your study area and illustrate your primary corridor.
6. You will be sampling along a grid extending beyond the peripheries of the identified primary corridor (Figure 1). The sampling grid will be somewhat a function of the area and should include 20-30 measurements along a 5 x 4, 5 x 5, or 5 x 6 grid (length x width). A wider grid (7 x 3) works well for open areas while a narrower grid (4 x 5 or 3 x 7) would be useful for an area confined to a narrow trail or road. Note your grid setup and try to start at the skiers left corner of your grid nearest your starting point (bottom left in map view). Make a note of this ('SW corner, next to Highway 431').

7. Your grid measurement points should be equally spaced based upon the area you are sampling and should be no closer than 3 meters (~10 feet) and no further apart than 10 m (~30 feet). Ideally, a spacing of 5-7 meters (~20 feet) should be good and can be thought of as 5-7 strides on your skis.
8. Enter the grid dimensions in the MHApp as a note.
8.5. Add a photo for reference and illustration on each post on MHapp (see example image below).
9. If it turns out to be a major pain to enter each measurement in the MHApp (your feedback will be valuable in this regard), follow the same protocol listed in steps 6-8 and 10-11 (below) and use a notebook to record the values. Using your phone or computer at home, sum up the values and divide by the total number of samples to calculate the mean. Enter this in the MHApp, but save your data so we can do other calculations at a later time. [note: according to MHApp team, this may still be complicated with current version. "A work-around here if someone does not have a smartphone, is someone can still enter this information into their notebook in the field, but someone that DOES have a phone needs to transcribe this info into the mobile app and use the location adjuster in the app to record the location properly."
10. Measure and record the snow depth to the nearest centimeter by inserting the probe vertically into the snow. It is usually best to repeat each measurement two-three times within a meter of where you are standing (think turn left, measure, reach out straight ahead, measure, and turn right, measure). If the measurements agree to within 5 cm, call it good. In shallower snow conditions, this will enable you to avoid erroneous depths due to rocks or logs and stumps. Stop when you feel some resistance. If you have to push hard, check the probe tip to see if it is muddy, indicating that you might be pushing in to saturated soil. If it is clean, you are probably breaking through a crust. Record each value.
11. Using a zig-zag pattern (Figure 3), continue sampling along your grid. If a boulder, creek, or some other impediment exists at a sample point, note this and either adjust your sample point accordingly or skip the point and enter X (so we can differentiate between 0 depth and an object);
12. Along the way, note (and photograph if you'd like!) any observations such as bare soil, vegetation damage, exposed soil that has been brought to the surface, creeks, or riparian areas. A major goal of this work is to keep trailheads open by helping to preventing damage when they should be closed. This comes from knowing something about the snow depth variability!
13. At home (or in the field if using the MHApp), input your measurements into Mountain Hub.
14. Repeat whenever you feel psyched!
15. In your spare time, it would be helpful if you put in locations where you know OSV's are being staged. Make a note if these trailheads are official or unofficial. This will be very helpful for me in figuring out nearby weather stations.
16. Some things to keep in mind: This is a starting point to gain some basic data and is not a highly-controlled science experiment (yet). To get to that level, you would need to bring a measuring tape and sample over a randomized grid. The more notes and photos you take documenting your measurements, the better we can understand which trailheads will need the higher precision measurements and the better we can make the next iteration of this protocol. **Even just a few data points are better than none! If you only have time to make three measurements and report the average of them (sum them up and divide by three), that is way better than no data!**

Your feedback on this protocol is welcome and encouraged. Please let us know any issues or things that could be explained better.

Figure 1: Example photograph (mimicking a panorama but using Google Earth) showing a possible study area. On the map view, you can denote your primary area of study.

<table>
<tr><td>Location</td><td colspan="4">Mount Rose</td><td>Date/Time</td><td colspan="3">1-Jan-27, 2:15 pm</td></tr>
<tr><td>Latitude</td><td colspan="2">39.300°N</td><td>Longitude</td><td colspan="2">119.921° W</td><td>Elevation</td><td colspan="2">2622.0</td></tr>
<tr><td>Aspect</td><td colspan="5">Flat with slight S exposure</td><td>Grid Size</td><td colspan="2">5 x 4</td></tr>
<tr><td>Weather</td><td colspan="8">Partly cloudy, light N wind, cold, 15 cm new snow two days ago</td></tr>
<tr><td>Notes</td><td colspan="8">50% moderately compacted, 40% untracked snow, 10% very compacted</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td colspan="9"></td></tr>
<tr><td>Grid</td><td>Row</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Point</td><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>G</td><td>H</td></tr>
<tr><td>1</td><td>81</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>77</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>78</td><td>82</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>77</td><td>80</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>69</td><td>66</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 2: Notebook layout (Excel spreadsheet) with data entry examples. If you don't use centimeters, make a note of that! Note that in Figure 3 the zig-zag path of sampling will cause you to fill out row B in reverse (starting from point 5 and working backwards).

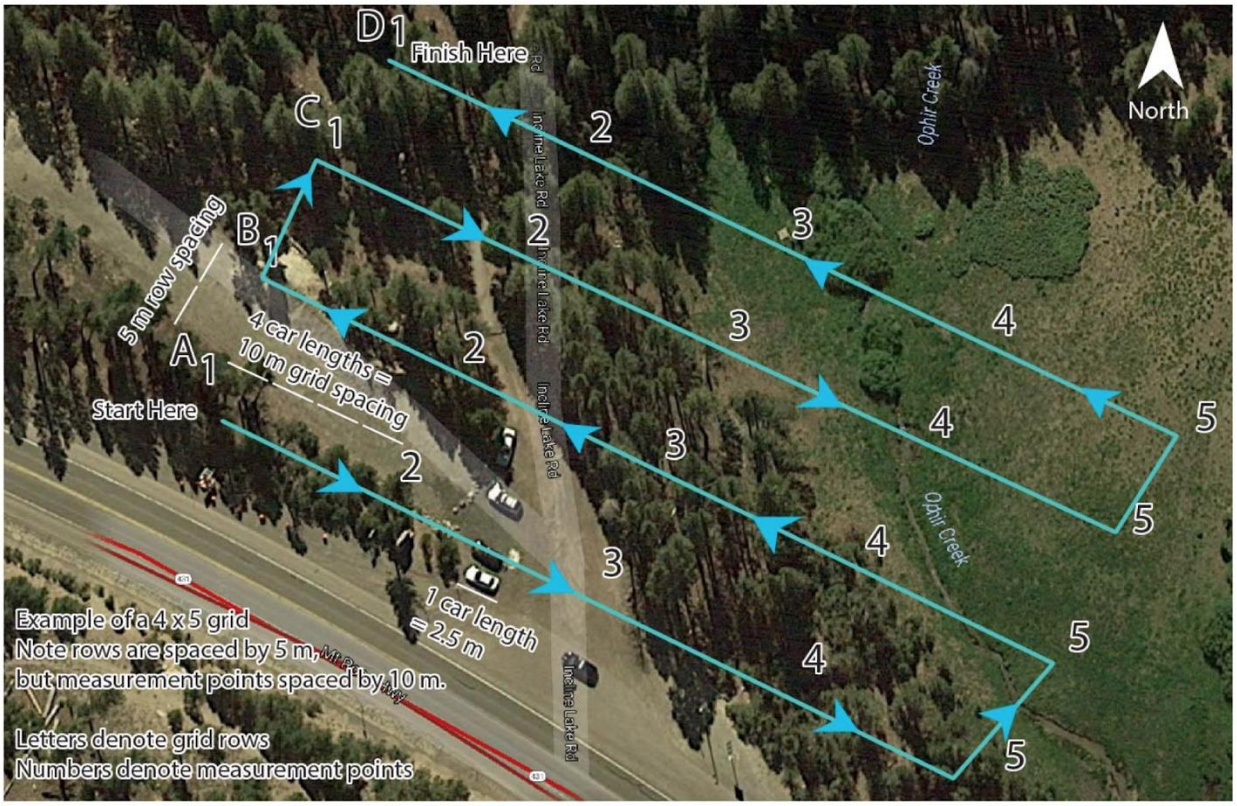

Figure 3: Map view of example sampling pattern. Note that rows are spaced 5 m apart, but measurement points along the row are spaced 10 m. Whatever works is fine as long as you make a note of how you did it! I picked this spacing here to show how you could cover the main staging area, two possible trails, plus a clearly sensitive riparian and meadow area. If you make a quick map for your sampling efforts, it will be helpful in evaluating your collected data.