Author response to reviewer and public comments for Brief Communication: Differences between Sundowner and Santa Ana wind regimes in the Santa Ynez Mountains, California" by Benjamin J. Hatchett et al.

Responses to reviewer comments are given in **bold**
New or changed text is given in *italics* (***bold italics*** for emphasis where noted)

Interactive Comments from Anonymous Reviewer #2

1. The authors propose a simple method for the detection of Sundowner events from surface temperature observations. From the chosen events, the authors build a climatology for the Sundowner winds. This climatology is compared against a pre-existing Santa Ana index. The paper is well written but presents a very basic analysis. The three dimensional dynamics of the phenomena is missing and can be performed using reanalysis data without the need for further downscaling. The authors fail to provide a clear physical and dynamical description of the differences between the two phenomena. This leads me to not recommend the publication.

We appreciate the reviewer taking the time to evaluate our paper and provide constructive suggestions for improvement. Our analysis is indeed basic, and we believe in the Occam's Razor approach to doing science. In this case, two simple indices (one for Santa Anas and one for Sundowners) show markedly different synoptic setups, which has not been previously shown. We have made a concerted effort to improve the dynamical explanation of the differences between the phenomena, however a detailed explanation of each phenomena is beyond the scope of this short paper. Such descriptions can be found in previous work for Santa Anas (see references within the paper) and in the case of the Sundowner, we added additional analysis and noted in the original manuscript that a more detailed modeling study is the subject of continuing research (Smith et al. in revision for Journal of Applied Meteorology and Climatology).

Our primary goal with this paper was to use a simple, or basic, index to differentiate these two important downslope windstorm phenomena in Southern California in terms of seasonality and synoptic structure, as written in the original final paragraph of the introduction: "We hypothesize that Sundowner events are seasonally distinct from SAWs and have differing synoptic scale patterns associated with them."

We respectfully disagree with the reviewer that the three dimensional dynamics can be performed using a reanalysis product due to the small scale of the Santa Ynez mountains. All readily available reanalysis products are in the 30-60 km horizontal resolution, and the Santa Ynez are only approximately 5 km in width and 1 km in height. Mountain wave dynamics in large mountain ranges, such as the Sierra Nevada, Rocky Mountains, Himalaya, or Andes could feasibly be well-resolved by reanalyses. This is why we are performing 2 km downscaled simulations akin to Cannon et al. 2017 but for a ten year period.

Another primary limitation in the analysis is the lack of upstream observational data. The nearest radiosondes upstream of the Santa Ynez are found in Reno and Oakland and is certainly not representative of the upstream environment.

We added another instance to note this major limitation in our conclusion:
"Our findings are limited by the lack of upstream observational data and the small scale of the Santa Ynez mountains, which limits the ability of reanalysis products such as NARR to evaluate the three-dimensional characteristics of Sundowner winds."

We believe the reviewers comments to valid and valuable, and as will be shown below, we have added significant analyses to address their concerns.

2. The Sundowner winds are downslope wind storms and the dynamics of such winds has been described in the literature since early 1950's (e.g. Scorrer 1955; Clark et al. 1977; Klemp and Lilly 1975; Smith1979, 1985; Smith et al. 1993; Durran 1986, 1990; Vosper 2004; Grubisic and Billings 2007, 2008; Jiang and Doyle 2008; Doyle et al. 2011). There are several examples, in the literature, of flow characteristics and approximations which allow the description of the dynamics of such phenomena even with low resolutions such as reanalysis. The differences in the dynamics, upwind characteristic of the flow and boundary layer differences between the Sundowner and Santa Ana are missing from the manuscript and should be provided

We appreciate the reviewer's suggestion to further evaluate the differences and have now performed an additional analysis using NARR (see below). We also appreciate their provision of a compendium of downslope windstorm references, however given the length limitations for number of references in the NHESS guide to authors for brief communications, we were only able to add the most comprehensive of these (of course, if the reviewer has a special request or two, we have no issue with a substitution). It should be noted that this paper was never intended as a comprehensive literature review on downslope windstorms due to its short format and we did include the key relevant southern California downslope windstorm papers in the original manuscript.

We added the following text (bold italics) to ensure that readers are aware of ongoing efforts (Smith et al. in revision) to better understand the mesoscale dynamics of Sundowner winds:
"The 32 km horizontal resolution of NARR precludes a finer-scale analysis of how coastal winds and topography interact to produce Sundowners and is the subject of continuing research using a 10 year, 2 km horizontal resolution downscaled climatology produced with a numerical weather prediction model ***(Smith et al. in revision)***. ***This study aims to more comprehensively address the sub-synoptic dynamics of Sundowner wind events."***

We understand the reviewer's concern that we did not provide abundant analysis of dynamics (though no scale of dynamics of interest is provided by the reviewer, so we are assuming they mean mesoscale), upwind characteristics, or boundary layer differences. That

was never our intent, as we merely wished to demonstrate the large (synoptic) scale differences between these wind regimes. We apologize for our lack of clarity and have altered the title accordingly so as not to mislead readers:

"Brief Communication: *Synoptic-scale* Differences between Sundowner and Santa Ana wind regimes in the Santa Ynez Mountains, California"

We would like to point out that the original text made our key goals (to differentiate synoptic scale differences between the two regimes) clear (bold for emphasis):
"Here we use observational data and atmospheric reanalysis products to produce a climatology of Sundowner winds in an effort to broaden the understanding of when and **under what synoptic conditions** Sundowner winds occur and to relate them to the well-studied SAWs. We hypothesize that Sundowner events are seasonally distinct from SAWs and **have differing synoptic scale patterns associated with them**."

The response to the following comment includes our new regarding the inclusion of the reviewer's suggestions to more thoroughly examine upstream and vertical characteristics of the flow regimes.

3. The manuscript also, does not provide any analysis of the atmosphere's vertical profile. Although this analysis may be difficult with the NECP reanalysis if model levels are not available, this would not be the case with the Japanese 55-year Reanalysis (JRA-55) or the Modern Era Retrospective-analysis for Research and Applications (MERRA2) which have similar horizontal resolutions to NCEP with 60 and 72 model levels respectively. Both are freely available for research. The analysis of the atmosphere's vertical structure would allow a better understanding of the phenomena and provide clues to the differences between Sundowner and Santa Ana winds. This should be added.

The reviewer makes a valuable suggestion to examine the vertical structure of the atmosphere. However, the problem is not one of vertical resolution, it is one of horizontal resolution with respect to the small spatial scale of the Santa Ynez mountains. If a model does accurately resolve terrain, it will not correctly simulate atmospheric motions even if it has infinite vertical resolution of model levels (see for example, Smith et al. 2013). This is a key limitation for mesoscale mountain wave phenomena. If the reviewer could point us towards specific literature that proves that gravity wave breaking produced by 1 km high by 5 km wide 2-d mountain can be resolved by a 30-60 km horizontal resolution model (and not a large mountain range as previously noted), we would appreciate it.

We added text to highlight these aspects in the introduction and to introduce our additional analysis of vertical profiles along a transect orthogonal to the study region:
"Although our primary goal is to explore synoptic scale differences between wind regimes, Cannon et al. (2017) pointed out the importance of northerly winds in Sundowners, which we would expect to be absent during SAW-only regimes. To do so, we examine vertical cross sections of northerly (v-component) winds from 32°N-36°N at levels between 1000 hPa and 300

hPa from NARR. The coarse resolution of reanalysis products prevented us from attempting to identify overturning isentropes that are a key signature of mountain wave-induced gravity wave breaking (Smith et al. 2013; Cannon et al. 2017). Low level (925 hPa) winds were composited to compare the spatial extent and magnitude of northerly winds, particularly offshore, during Sundowner and SAW events."

We added this sentence about the limitation of using reanalysis for vertical profiles in the summary:
"Our findings are limited by the lack of upstream observational data and the small scale of the Santa Ynez mountains, which inhibits the ability of reanalysis output to comprehensively evaluate the three-dimensional characteristics of Sundowner winds."

Despite these limitations, we used NARR to produce horizontal cross sections orthogonal to the Santa Ynez to highlight the differences in vertical v-component winds. As mentioned above, examining potential temperatures in a composite sense plus the poor ability of a coarse model to capture orography would limit identification of vertical or overturning isentropes that characterize gravity wave breaking. The previous text noted the issues with NARR, but we are now more explicit about our ongoing work.

New text in bold italics:
"The 32 km horizontal resolution of NARR precludes a finer-scale analysis of how coastal winds and topography interact to produce Sundowners and is the subject of continuing research using a 10 year, 2 km horizontal resolution downscaled climatology produced with a numerical weather prediction model ***(Smith et al. in revision). This study aims to more comprehensively address the sub-synoptic dynamics of Sundowner wind events.***"

We did find interesting results (the presence of a low level jet offshore and the strong northerly cross mountain flow present in Sundowner but absent in Santa Ana only), and we thank the reviewer for encouraging us to pursue an examination of vertical structure.

We added the following paragraph (figures below) regarding these results:

"*Focusing on the low level (925-hPa) winds near the California Bight, the presence of a 12 ms^{-1} north-northwesterly coastal jet is observed offshore of California with northerly flow in the region of the Santa Ynez during Sundowner-only events (Figure 4a,c). The coastal jet is a climatological feature of the east Pacific (Doubler et al. 2015) and may have a role in creating Sundowner winds if this offshore momentum is advected eastward, producing strong cross-mountain flow over the Santa Ynez. This low-level jet feature is absent during SAW-only events and the flow throughout the offshore portion of the domain has a larger easterly component, particularly over California (Figure 4b,d). Vertical cross sections are consistent with the low-level coastal jet offshore of California and winds between -5 and -7.5 ms^{-1} above and downstream of the terrain near Santa Barbara during Sundowner-only conditions (Figure 5a,c). This is consistent with the case studies of Cannon et al. (2017) and the requirement for strong cross-mountain flow in downslope windstorms (Smith 1979; Durran 1990). Composites for SAW-only* *events indicates weak to no northerly wind (0 to -2.5 ms^{-1}) in the vicinity of Santa Barbara (Figure 5b,d). SAW events show stronger momentum aloft, consistent with the tighter midtropospheric geopotential height gradient (Figure 3c,f) compared to Sundowner-only events (Figure 3a,d).”*

New text in summary paragraph:
“Sundowner-only conditions demonstrated the presence of a low-level northerly coastal jet that was absent during SAW-only regimes.”

Again, we want to re-iterate that the purpose of this paper was to show that large scale synoptic patterns between two fire weather regimes are different and not to perform a comprehensive dynamical analysis of the regimes. That work is part of a much longer paper currently undergoing revision (Smith et al. in revision for Journal of Applied Meteorology and Climatology). If the reviewer would like to contact us directly to discuss the findings of Smith et al., we encourage them to do so as it appears they would find this paper to be of interest. The goal of the current short communication paper is to share the broad differences between these fire weather regimes to a variety of science and natural resource management communities as well as the general public. This is consistent with the NHESS aims and scope (https://www.natural-hazards-and-earth-system-sciences.net/about/aims_and_scope.html).

New Figure 4:

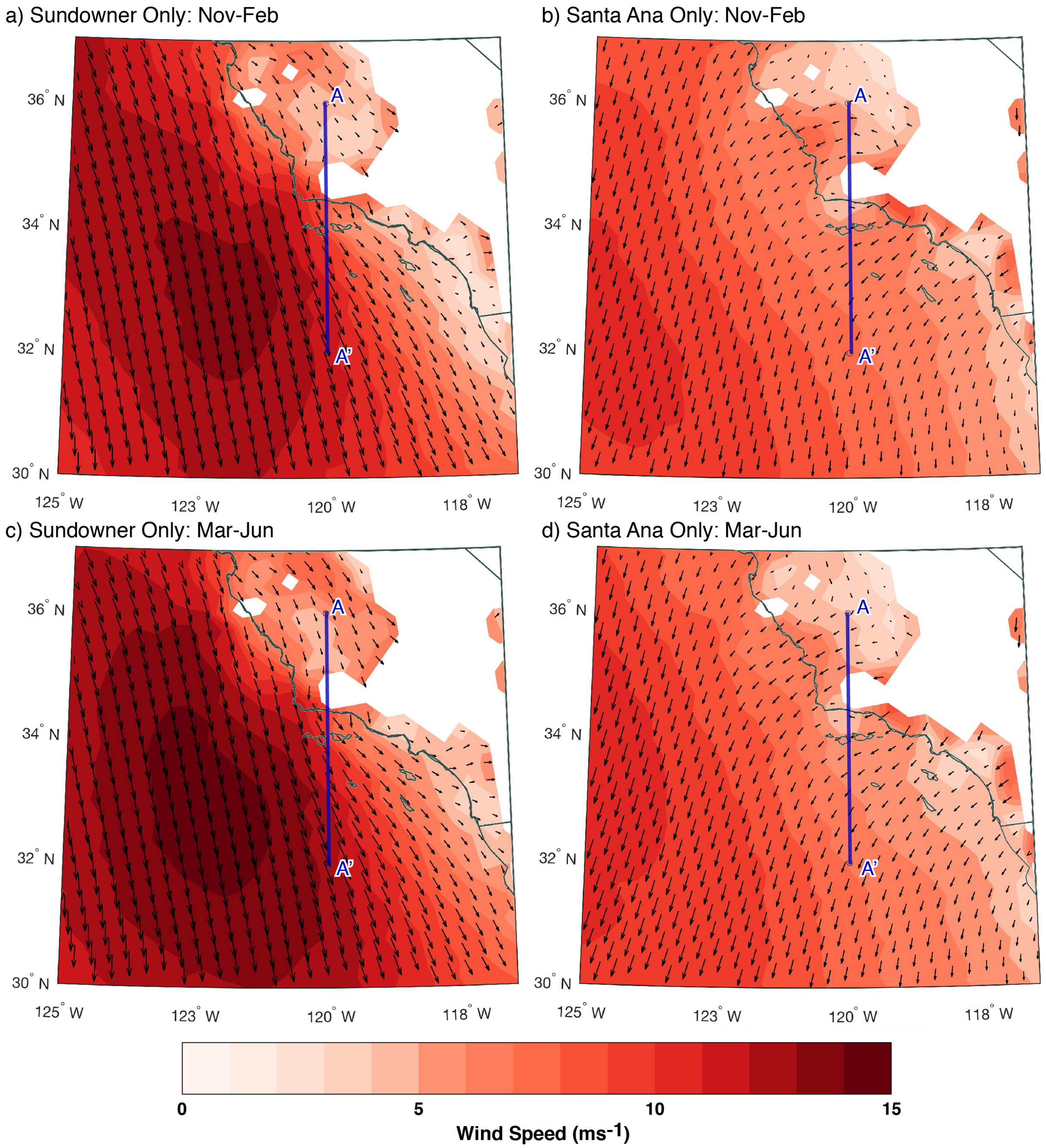


Figure 4: (a-**d**) Composite North American Regional Reanalysis **925** hPa **wind velocity magnitudes** (filled contours**, contour interval 1 ms^{-1}**) **with vectors showing total wind direction (vector size is proportional to wind magnitude). Shaded white areas indicate areas where NARR terrain exceeds 925 hPa. The dark blue lines in each panel indicate the extent of the cross section used to produce the vertical cross sections shown in Figure 5.**

New Figure 5:

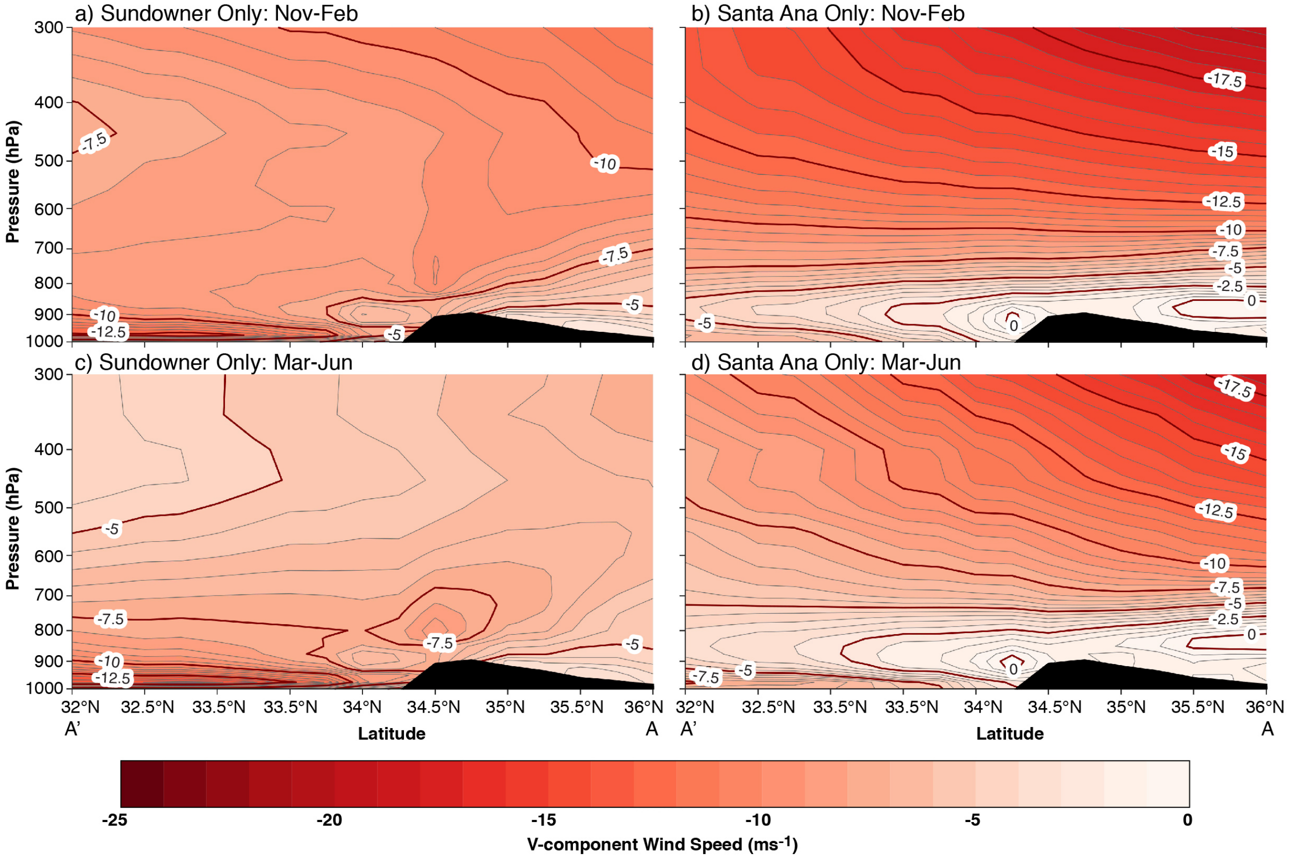


Figure 5: (a-d) Composite North American Regional Reanalysis northerly (v-component) winds (filled contours; thin contour interval 0.5 ms^{-1} thick contour interval 2.5 ms^{-1}) for the cross-section spanning 32°N-36°N through the center of the study area longitude of 120°W. Black areas denote NARR terrain.

Minor Comments:

4. A description of the SAW index should be more elaborate, so that the reader does not have to interrupt the reading of this paper and review Guzman-Morales et al. (2016) in order to understand the applied methodology.

We agree that this is a useful suggestion (please also see the Interactive Comment from Clive Dorman), and we have added additional text so as to help the reader understand the methods employed by Guzman-Morales et al. (2016) without requiring an interruption from reading the current paper:

New text in bold italics:

"The hourly SAW index used for comparison against our Sundowner climatology was developed for southern California by Guzman-Morales et al. (2016) using output from a dynamically downscaled regional climate model ***at 10 km horizontal resolution. Guzman-Morales et al. (2016) defined SAWs at each grid cell by first identifying winds with a negative u-component***

(between 0 and 180°) that exceeded the upper quartile of wind velocities at this cell. To be categorized as a SAW event, they required a 12-hour period of continuous winds that had at least one hour when velocity exceeded the grid cell velocity threshold. They allowed discontinuities of up to 12 hours to account for breaks in SAWs, and their index reflects the regional average wind speed during periods of time that satisfied the direction-magnitude-continuity study design."

5. There are several time periods referred in the text: 1979-2014, 1981-2010, 1997-2014. Figures 1, 2a, 2b and 3 should be for the same time period, either 1979-2014 or 1981-2010.

We understand the reviewer's concern, as there are many time periods used in the study. In the spirit of comprehensive science, we prefer to perform climatological studies using all available data, which regrettably may not always line up with other datasets or model output availability.

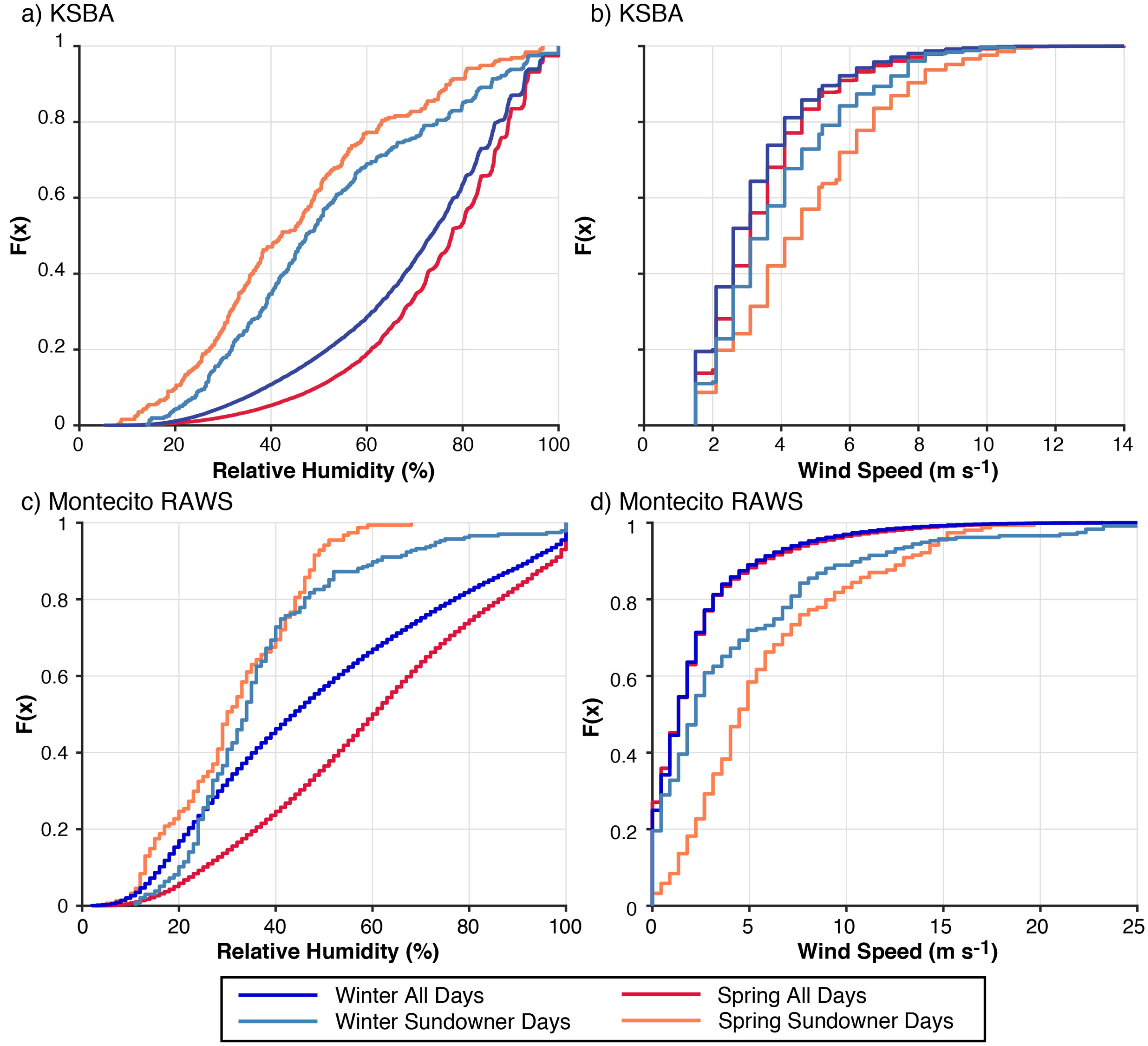
With regards to changing the time periods of the analysis, we respectfully disagree with the reviewer in changing Figures 1,2, and 3 to the same time period, as 1981-2010 is a standard reference base period for performing climatological evaluations of climate normals and meteorological processes. The results do not change as a function of time period chosen and we defer to using all available data for our analysis and differencing our findings from reference periods used as climatological standards.

6. Figures 2c and d should be compared to 2a and b for the same time period, i.e. 1997-2014. I suggest adding the latter figures in supplementary material.

We believe that this an acceptable place to compromise on time periods. We changed Figure 2 to follow the suggestion of the reviewer, however we chose to add the original figure to the supplementary material and compare the same time periods in the text. We note the similarity in the main text:

"*For the period between 1997-2014 and during both the Sundowner and Santa Ana peak seasons"*
"These results are consistent whether the periods of Sundowners considered include 1997-2014 or 1979-2014 (Figure S1)."

The original Figure 2 is now found in the Supplementary material. New Figure 2:



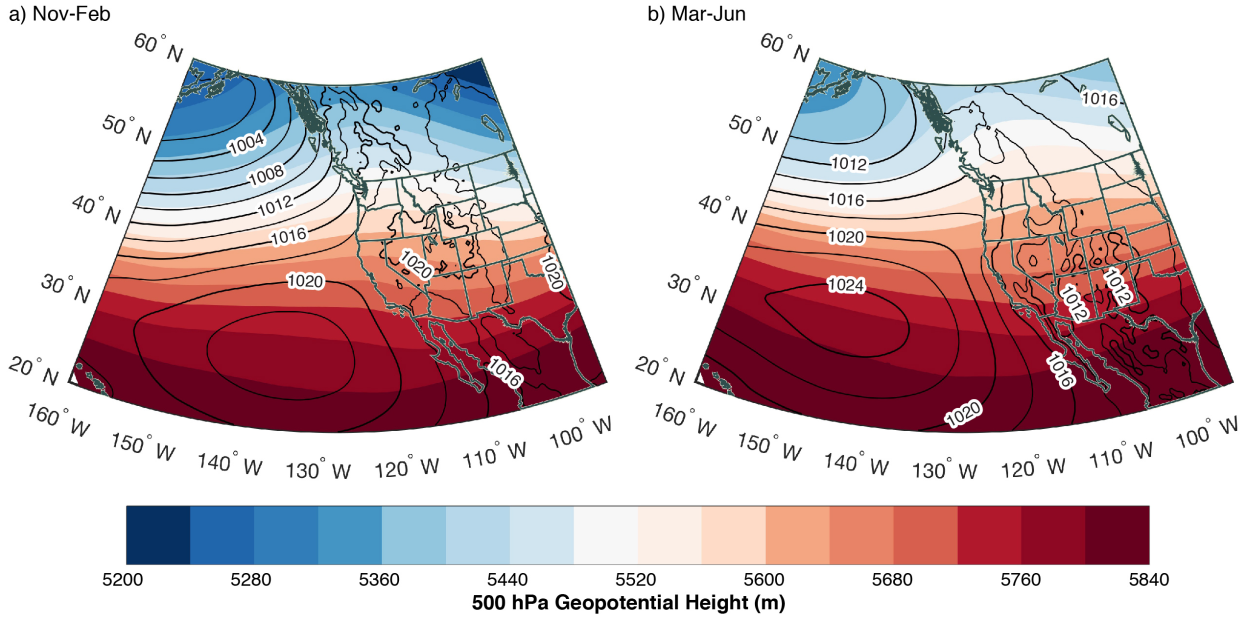
7. In figure 3 I suggest adding a composite of the 500hPa and mean sea level pressure for both seasons in order to facilitate the interpretation of the different differences.

Thank you for the suggestion, we have now added a composite for each season to the supplementary material (Figure S2). We also calculated differences for each season between Sundowner and Santa Ana Only events to further aid readers in interpreting the differences in 500 hPa geopotential heights and SLP (new Figure S3).

New text:

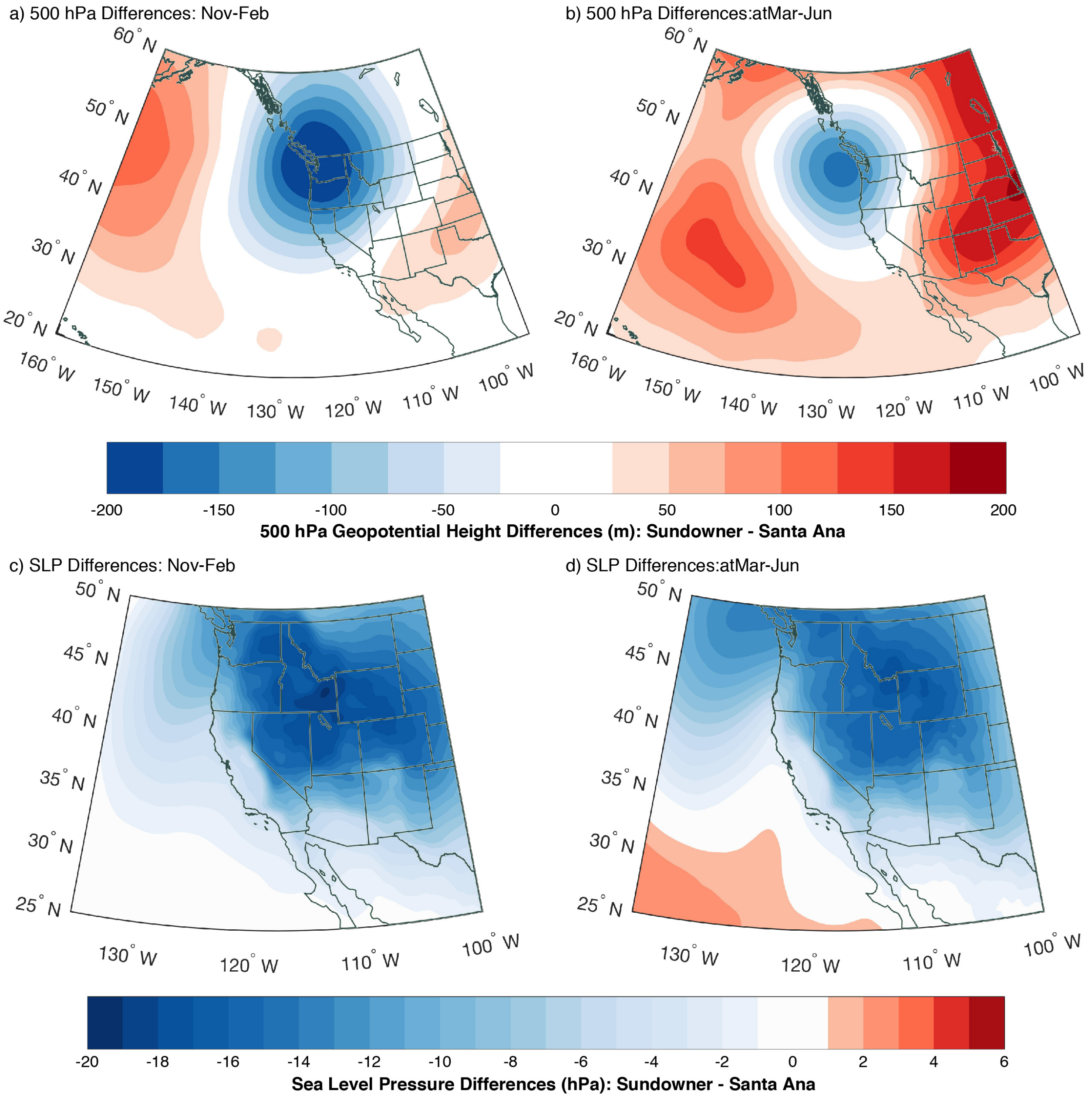
"For comparison, seasonal means of geopotential height and MSLP and differences between Sundowner-only and SAW-only for these fields are both provided in the supplementary material (Figures S2 and S3, respectively.)"

New figures and captions:


a) Nov-Feb

b) Mar-Jun

“Figure S2: Seasonal mean 500 hPa geopotential heights (filled contours, contour interval 40 m) and sea level pressures (contours every 2 hPa, thicker contours show 4 hPa intervals) for extended winter (a) and extended spring (b).”



"Figure S3: 500 hPa geopotential height differences between Sundowner Events and Santa Ana Only events during extended winter (a) and extended spring (b). Contour interval is 25 m. (c-d) As in (a-b) except for sea level pressure differences. Contour interval is 1 hPa."

Doyle, J.D., et al., 2011. An intercomparison of T-REX mountain-wave simulations and implications for mesoscale predictability. Mon. Weather Rev. 139, 2811–2831. Durran, D. R., 1986: Another look at downslope windstorms. Part I: The development of analogs to supercritical flow in an infinitely deep, continuously stratified fluid. J. Atmos. Sci., 43, 2527–2543. Durran, D.R., 1990. Mountain waves and downslope winds. Meteorol. Monogr. 23, 60–

83. Grubisic, V., Billings, B., 2007. The intense leewave rotor event of sierra rotors IOP8. J. Atmos. Sci. 64, 4178–4201. Grubisic, V., Billings, B., 2008. Summary of the sierra rotors project wave and rotor events. Atmos. Sci. Lett. 9, 176–181. Jiang, Q., Doyle, J.D., 2008. Diurnal variation of downslope winds in Owens Valley during the sierra rotor experiment. Mon. Weather Rev. 136, 3760–3780. Klemp, J.B., Lilly, D.K., 1975. The dynamics of wave induced downslope winds. J. Atmos. Sci. 32, 320–339. Mobbs, S. D., Vosper, S. B., Sheridan, P. F., Cardoso, R., Burton, R. R., Arnold, S. J., Hill, M. K., Horlacher, V. and Gadian, A. M., 2005: Observations of downslope winds and rotors in the Falkland Islands. Quart. J. Roy. Meteor. Soc., 131, 329-351 Scorer, R. S., 1955: The theory of airflow over mountainså̆AˇTIV. Separation of flow from the surface. Quart. J. Roy. Meteor. Soc., 81, 340–350. Smith, R. B., 1979: The influence of mountains on the atmosphere. Advances in Geophysics, Vol. 21, Academic Press, 87–230. Smith, R.B., 1985. On severe downslope winds. J. Atmos. Sci. 42, 269–297. Smith, R. B. and S. Grøna◦s, 1993: Stagnation points and bifurcation in 3D mountain airflow. Tellus, 45A, 28–43. Vosper, 2004: Inversion effects on mountain lee waves. Quart. J. Roy. Meteor. Soc., 130, 1723–1748

We appreciate the additional references, and although the NHESS guide to authors dictates a limit of 20 references for brief communications, we have added several to our manuscript where we believe them to be most relevant.

Added references:
Durran, D.R.: Mountain waves and downslope winds. Meteorol. Monogr. 23, 60–83, 1990.
Smith, R. B.: The influence of mountains on the atmosphere. Adv. Geophys. Vol. 21, Academic Press, 87–230, 1979.