Evaluating the Relationship Between Two Extreme Wind Events in Southern California for Advancements in Forecasting

Research Plan

Alana Ginsburg

Earth and Environmental Sciences

A: Rationale

The frequent extreme wind events in Southern California significantly influence local communities through dangerous gale force wind conditions and rapid wildfire spread (Ryan, 1996; Blier 1998; Hughes and Hall, 2009). Two downslope wind events in the region are Santa Ana Winds (SAWs), which impact the coastal counties of Southern California located south of Santa Barbara county, and Sundowners, which occur in Santa Barbara county.

Both SAWs and Sundowners are heavily influenced by the unique and complex topography of Southern California; the mountains in this region are known collectively as the Transverse Ranges. The region has many peaks and valleys, and is framed by the Pacific Ocean on one side and a large desert (Mojave Desert and Great Basin) on the other side. In Santa Barbara, these features are present at a smaller scale, with the additional presence of a coastline that runs horizontally west to east for 100 km. The Santa Ynez Mountains are parallel to this stretch of the coastline and are steep, with their peak elevation reaching around 1300 m (Ryan, 1996; Blier, 1998). The western mountain ranges create SAWs and the Santa Ynez mountains in Santa Barbara county create Sundowners (Ryan, 1996; Raphael, 2003).

Mechanistically, these extreme, downslope wind events are caused by mountain wave activity, and may be associated with other meteorological phenomena such as rotors, jump zones, wave breaking regions and the adiabatic warming of air parcels (Blier, 1998). Typical air flow around a mountain barrier consists of air being trapped on the windward side of the mountain. Downslope wind events represent an extreme in the conditions at the mountain barrier. These events occur when the atmosphere above the mountains is stable and properly stratified, and the geostrophic flow in the region is across the mountain tops due to the presence of an unusually strong pressure or thermal gradient on either side of the mountain barrier. Gravity waves transfer this mid-level momentum from the geostrophic flow occurring in the mid-troposphere to the surface, which creates strong leeward-side surface winds. These winds are known to be especially strong in areas just beyond mountain gaps (Blier, 1998; Hughes and Hall, 2009). The disruption in the stability of the atmosphere at the mountain barrier due to the abnormal geostrophic flow creates a critical level that traps the gravity waves that form on the leeward side of the mountain and causes the air parcels on that side to sink and compress quickly, creating the hot, dry winds of the downslope wind events (Ryan, 1996; Blier, 1998; Hughes and Hall, 2009)

Sundowners and SAWs bring hot, dry air into regions on the leeward side of a mountain. These conditions create a threat for wildfires, as hot, dry air is carried over mountains from deserts on the windward side into the leeward side that has abundant fire fuel (Ryan, 1996; Raphael, 2003).

SAWs are defined as being easterly, offshore winds that occur in Ventura, Los Angeles, Orange and San Diego counties primarily in the winter months (Raphael, 2003; Jones et al. 2010). SAWs tend to be more prevalent in winter because the thermal gradient between the desert and ocean on either side of the Transverse ranges tends to be stronger, as the desert is coldest in the winter and the ocean stays warm (Hughes and Hall, 2009). They are known for occasionally reaching hurricane speeds in canyons and mountains and passes, and their name stems from the Santa Ana mountain range, a section of the Transverse Ranges where Santa Ana winds are particularly amplified (Hughes and Hall, 2009; Jones et al. 2010; Guzman-Morales et al. 2016). In the past, SAWs have been defined using various variables and characteristics of forecasts and observed meteorological conditions. Raphael (2003) developed a 33 year long climatology of SAWs based on observed pressure gradients at mean sea level from station data, Jones et al. (2010) identified SAW events based on 28 years of daily Fire Weather Index and Guzman-Morales et al. (2016) used mesoscale modeling that utilizes model-derived wind data exclusively.

Sundowners occur most frequently in the late spring and derive their name from their tendency to occur in the late evening into early night hours (Blier, 1998). As the synoptic cause of Sundowners remains unclear, the definition that has been used for the wind event has undergone many phases. The first attempt to develop a universal definition for Sundowner severity accounted for temperatures outside the normal diurnal curves, and wind speed and direction at the coast and in the mountains and passes (Ryan, 1996). These criteria remained confusing for researchers and forecasters as they did not help to identify the cause of Sundowner events, so the Mean Sea Level Pressure (MSLP) gradient between Bakersfield airport and Santa Barbara airport was added as a telling factor to consider (Sukup, 2013). The most recent definition relies on atmospheric model output which is calculated with temperature differences and the north-south wind component at each grid cell to study these same characteristics that had been previously determined with station data (Smith et al. 2018).

Spatiotemporal trends for both wind events, SAWs more so than Sundowners, are generally well understood. However, much still remains unclear about the overlap of these two events both temporally and spatially.

In previous studies, only surface station data was available and/or used to examine Sundowners and SAWs (Ryan, 1996; Blier, 1998; Raphael, 2003; Sukup, 2013). While station data is still utilized, atmospheric reanalysis data is commonly used to further study climatological and meteorological questions. Reanalysis is created using weather observations and atmospheric model output to produce reconstructions of past weather conditions (Parker, 2016). In recent years, programs and computational models such as the Weather Research Forecasting model (WRF) have been developed and applied to allow for the collection of data in higher resolution for locations where winds cannot be detected with station data (Cannon et al. 2017).

In this study, reanalysis data was utilized to compare synoptic conditions between Sundowner and SAW events. The purpose of this study was to improve knowledge on the relationship between Sundowners and SAWs on spatial and temporal scales, which may ultimately advance the forecast skill of atmospheric models.

B:

Research Question:

1. How often do Santa Ana Winds or Sundowners occur in the days preceding or following Sundowners or vice versa?
2. What are typical synoptic meteorological setups when Santa Ana and Sundowner winds occur quasi-simultaneously?

Alternate Hypothesis:

Statistical results will exhibit that Sundowners have a significant tendency to precede the occurrence of Santa Ana Wind events and that Sundowners from PC2 occur more frequently than those at PC1.

Map analysis will exhibit that high pressure centers on days of Sundowner occurrence will be exhibited further west than high pressure centers on days of Santa Ana Winds. Winds on Santa Ana Wind event days will be more widespread, and a strong temperature gradient between the desert and ocean will be exhibited on Santa Ana Wind days and not on Sundowner days.

Null Hypothesis:

No observable differences will be recorded through temporal or map analysis.

Expected Outcomes:

Results will suggest a correlation between the two events, as they more often than not occurred within days of each other. However, variations in the results suggest that the difference in terrain and topography between the larger region and the specific region affected by each event is responsible for the unique characteristics attributed to each wind event.

C:

- <u>Procedures:</u>

a. Data Sets

This study will utilize various databases to provide information about days with Sundowners and SAWs and the associated synoptic conditions. The SAW database will be provided by Dr. Leila Carvalho using the methodology from Jones et al. (2010). The Sundowner database will be provided by Dr. Charles Jones. This database was produced by running a Principal Components Analysis (PCA) on wind components from the Weather Research Forecasting (WRF) model output. PC1 Sundowners exhibit generally northwesterly winds and are found to occur in the eastern region of Santa Barbara, and PC2 Sundowners exhibit generally northeasterly winds (Jones et al. 2020). These two databases will serve as a foundation for the creation of more comparative databases related to temporal differences in the occurrence of these events.

b. Data Grouping

In this study, Sundowner wind events will be considered in 3 ways: all Sundowner wind events accounted for by the first PCA only (PC1 Sundowners), Sundowner wind events accounted for by the second PCA only (PC2 Sundowners), and Sundowners accounted for by either of the PCAs or by both PCAs (Sundowners). To clarify, the term Sundowner wind events can be assumed to account for the last of these options unless otherwise noted.

Based on this model, numbered groups of common temporal setups based on the dates of occurrence of a SAW event and a particular type of Sundowner that are in close temporal proximity to each other will be established. These lists will be composed of dates where wind events occur in close temporal proximity to each other.

c. Map Creation

For each group, 5 composite maps will be created for the following parameters: 500 and 850 hPa geopotential height, 1000 hPa vector winds, air temperature in degrees Kelvin at 1000 mb, and mean sea level pressure (MSLP).

Composite maps will be created to evaluate synoptic conditions when Sundowners and SAW events occurred within days of each other. Data for these maps will be sourced using North American Regional Reanalysis data (Mesinger et al. 2006) through the Earth System Research Laboratory (ESRL) Daily Average Composite Map creator.

- <u>Risk and Safety</u>

No known potential risks and safety precautions are relevant to the conduction of this study.

1. *Human participants research: N/A*
2. *Vertebrate animal research: N/A*
3. *Potentially hazardous biological agents research: N/A*
4. *Hazardous chemicals, activities & devices: N/A*

- <u>Data Analysis</u>

a. Temporal Analysis/Descriptive Statistics

JupyterLab (version 0.35.4) with Python languages (Numpy, Pandas, CSV) will be used to identify dates to create the lists for each group. Datasets will be subset accordingly.

Statistical analysis will be conducted to evaluate the frequency of overlap between the two wind events. The frequency for how many times each group occurs will be recorded. General percentages, a frequency comparison and means will be analyzed through Microsoft Excel.

b. Map Analysis

The composite maps created will be analyzed quantitatively and qualitatively in order to fully identify similarities and patterns in atmospheric setups during periods with the two wind events occurring in close temporal proximity.

Trends and features present in the map will be identified based on the colors and pattern shown in the ESRL model and will then be discussed. A general analysis of what is present will be done to further determine what kind of statistical analysis tests would be worthwhile.

d. Results Presentation

Graphs depicting the results will be made in either Microsoft Excel or through Jupyter Lab using Python.

<u>D:</u> Bibliography

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Project Summary

C.

- <u>Procedures:</u>

  b. Data Grouping

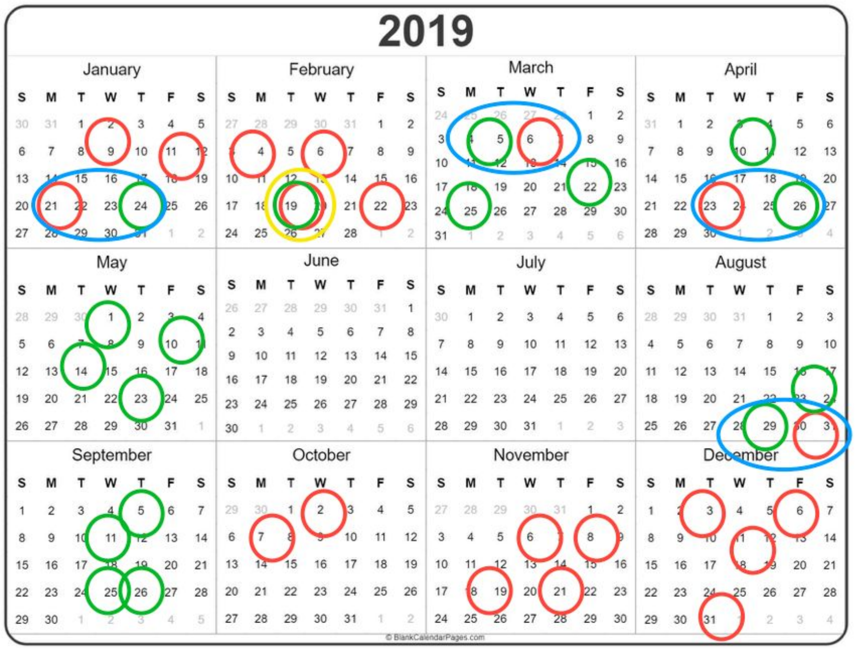

Figure 1: Model Calendar (Made by author)

Figure 2 shows the model calendar created following the conduction of a general analysis of the datasets in order to determine the groups that would be analyzed in the study. The model is based on hypothetical dates of events where Sundowner winds or Santa Ana Winds were observed to have occurred, which were hypothesized based on the annual tendencies of the original datasets***. Red circles represent dates of Santa Ana Wind events and Green circles represent dates of Sundowner wind events. Blue ovals represent times when both events occurred in close proximity to each other and yellow circles represent times when they occurred on the same day.***

Once the implications of this calendar were determined, the creation of numbered groups composed of lists of dates where the wind events occurred in close temporal proximity to each other became possible. ***Groups were established based on three possible time differences, and further differentiated by whether a SAW or Sundowner-type was occurring first, and what***

type of Sundowner the list was based off of. These lists each formed an original dataset. ***The dates included in the dataset for the group represent the latter event of the set of wind events that was preceded by an event of the other type. For example, Group 1 represents a list of dates where a Santa Ana Wind event was recorded 1 day after a Sundowner (PC2) was recorded. Table 1 exhibits the list of groups that were evaluated in the study.***

Fifteen possible setups of overlap between SAWs and each type of PC-classified Sundowner were defined as groups. These group definitions are based on an event that occurs on the recorded date, an event that precedes that date, and the lag time between those two events. Three control groups not listed in the table were also developed so the synoptic conditions found for the significant situations could be compared to the typical climatology of the general region. Seasons for the control groups were determined based on the established typical monthly frequencies of each wind event (Hughes and Hall, 2009; Jones et al. 2010; Raphael, 2003).

Group #	Event on Date	Preceding Event	Difference in Days
1	Santa Ana Wind	PC2 Sundowner	1
2	Santa Ana Wind, PC2 Sundowner		0
3	Santa Ana Wind	PC2 Sundowner	2
4	Santa Ana Wind, PC1 Sundowner		0
5	Santa Ana Wind	PC1 Sundowner	1
6	Santa Ana Wind	PC1 Sundowner	2
7	Santa Ana Wind, Sundowner		0
8	Santa Ana Wind	Sundowner	1
9	Santa Ana Wind		2

10	PC1 Sundowner	Santa Ana Wind	1
11	PC1 Sundowner	Santa Ana Wind	2
12	PC2 Sundowner	Santa Ana Wind	1
13	PC2 Sundowner	Santa Ana Wind	2
14	Sundowner	Santa Ana Wind	1
15	Sundowner	Santa Ana Wind	2

Table 1: Table of Group Characterizations (Made by Author)