The Effect of Ground Terrain on Sacramento Valley Supercells

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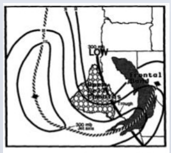
Introduction

Tornadoes in the Central Valley of California occur during the winter months, generally after the passing of cold fronts, under a mid level cold pool environment. In this environment, typically an ample amount of low level shear and a relatively weak amount of SB CAPE is in place. The narrow central valley allows for topographic channeling and the backing of surface winds, which can help to amplify low level shear. The narrowness of the central valley also contributes to another unique factor, where long lived supercellular thunderstorms that form in the post frontal environment eventually migrate eastward, and interact with the high relief terrain of the Sierra Nevada foothills. While it is known that supercells that migrate to the mountains run out of instability due widespread orographic precipitation, and the fact that the high mountains can interfere with the storm's air currents and essentially tear it apart, in the lower foothills, where the storms can still survive, the effects of the terrain on the supercell are far understudied.

[Fig 1] Sacramento Valley tornadoes in 2011, one of the most active years. (TornadoHistoryProject)



[Fig 2] Synoptic setup for post frontal convection (Monteverdi et al 1994)

Methodology

The methodology of this study occurs in 2 phases:

1. Verification of post frontal conditions
   - Find exact time, date and location of tornadoes
   - Look at 5 primary parameters for time/date of tornado
     - Surface temperatures of 10ºC to 20ºC
     - 500mb temperatures of -25ºC to -40ºC
       - Confirms steep lapse rates associated with convection
     - Surface Based CAPE
       - Weak inland SB CAPE values less than 500J/kg
       - Slightly higher SB CAPE values offshore, usually higher than 500J/kg
     - Surface winds
     - 700mb winds
       - Verifies presence of directional shear
   - (NCEP North American Regional Reanalysis Plotting Tool)

2. Correlation of the maximum positive change in gate to gate shear found in the level II radar velocity data (abbr. ΔGTG) to the relief in the terrain.
   - ΔGTG: Maximum increase in Gate to Gate shear on radar within 15 minutes of tornadogenesis
   - MPCEC (maximum positive continuous elevation change): Mesocyclone path during two frames of ΔGTG is traced in Google Earth. The base to peak height of the highest hill or cliff facing upstream is the MPCEC.
   - ΔGTG and the MPCEC will be plotted against each other on a graph to determine possible correlation.
   - COO: Coefficient of orientation is a measure of the orientation of the valley. It is calculated as:

$$COO = \sin([Angle\ of\ Channel\ \{AS\}] - [Angle\ of\ Storm\ \{AS\}])$$

   - COO is multiplied to MPCEC to get Index of Topographic Favorability (ITF), which is correlated to ΔGTG

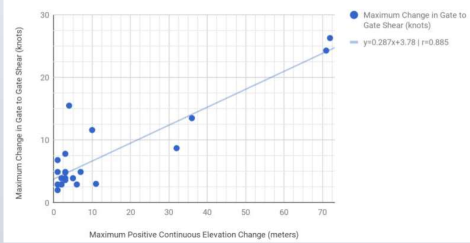
Data

[Table 1] Environmental, Radar Determined, and Topographical Characteristics of Tornadoes Influenced by Topography*
(Google Earth, ESRL NARR, NCEI Storm Events Database, Radar Data)

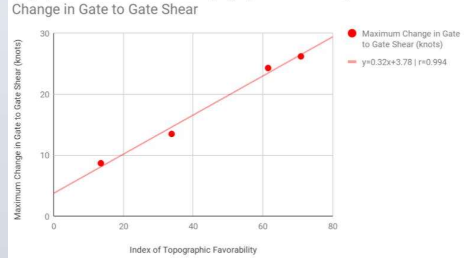
Case #	Date and Time	Location (CA)	GTG (kt)	ΔGTG (kt)	MPCEC (m)	Surface Wind	700mb Wind	SB CAPE (J/kg)	Surface Temps (°C)	500mb Temps (°C)	Angle of channel (degrees)	Angle of Storm (degrees)	COO	ITF
1	03/08/10 4:25pm	Chrome	33.0	24.3	71	SW	W	150	11	-31	275	155	0.866	61.5
2	05/25/11 6:45pm	Wicks Corner	21.4	8.7	32	SSE	WSW	200	14	-30	290	265	0.422	13.5
3	10/22/12 4:30pm	Grass Valley	30.1	13.5	36	SSE	WSW	100	14	-18	315	245	0.940	33.8
4	12/24/15 3:00pm	Folsom	38.8	26.3	72	SSW	W	250	12	-28	240	160	0.984	70.9

*For concision, only the 4 tornadoes with the highest MPCEC are included in this data table.

[Fig 3] The Relationship Between the Change in Elevation and the Change in Velocity Difference for a Supercell Mesocyclone



[Fig 4] The Effect of Index of Topographic Favorability on the Maximum Change in Gate to Gate Shear



The trends in both figure 3 and figure 4 generate p values less than 0.01, making them statistically significant.

Analyzing figure 3, we can see that out of the 26 mesocyclone induced tornadoes that were studied, there were two types. The mesocyclones between 1 and 20 meters are what we can consider as normal. They completed their entire life cycles in the valley, and never experienced the effects of the mountains. They still produced tornadoes, but they never experienced the intensification that the mountains can bring.

The other type of mesocyclone is much less common, only having occurred that 4 times in the historical radar record. This type of mesocyclone makes it into the mountains and encounters steep terrain which intensifies it rapidly. This is not to say that mesocyclones that run into mountains are stronger, but rather that they have a chance of intensifying faster. Storms that run into a relief change of 20m or higher have a possibility of intensifying faster, but this does not mean they will reach the same strength as those that form under normal, flat, conditions.

Discussion

There are two possible explanations as to why topography can increase the rate of intensification of a mesocyclone. The first explanation is the stretching of vorticity. In figure 13, it was apparent that the tornado had run into a hill, which may have caused the updraft speed to increase. This enhancement of updraft speed can give rise to low level vorticity stretching, enough for a marginal supercell to intensify quickly and produce a tornado. This would be supported by the strong correlation between ITF and ΔGTG in figure 4, with channels that are oriented perpendicular to storm motion producing the fastest intensifying updrafts.

Another explanation is topographical channeling. In high relief terrain, often times erosion channels can help create localized areas of topographical channeling which can orient surface winds in a much more favorable direction for locally enhanced low level shear. Enhanced low level shear can often mean a faster intensifying mesocyclone. This intensification can cause an increased likelihood of a storm producing a tornado.

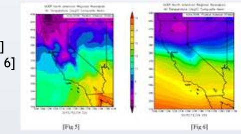
The results of this study do not suggest that every single storm that moves into the mountains will intensify, but rather that the probability of intensification of rotation is higher. There is always the possibility that a storm moving into the mountains will experience an unfavorably oriented topographic channel, that could disrupt the supercellular nature of a storm. Extremely steep levels of relief also tear apart storms as the move into the very high elevations. Even though there is a clear trend, there are always outliers. This being said, based on the case study and data, there is likely a positive correlation between steep relief and mesocyclone strength.

Case Study – December 24, 2015

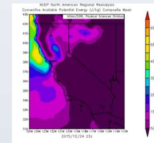
1. Verification of Post-Frontal Environment

a. Thermodynamic Environment

Warming surface temps [Fig 5] and cold mid level temps [Fig 6] show sufficiently steep lapse rates.



[Fig 5] [Fig 6]

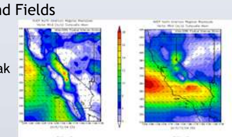


[Fig 7]

Verifying Surface Based CAPE shows open cell convection offshore with weaker inland CAPE [Fig 7].

b. Wind Fields

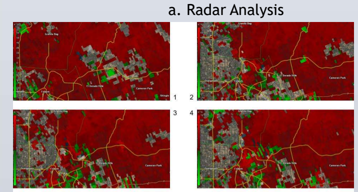
SW surface winds [Fig 8] and W 700mb winds [Fig 9] confirm marginally veering winds and weak directional shear.



[Fig 8] [Fig 9]

2. Radar and Topographical Analysis

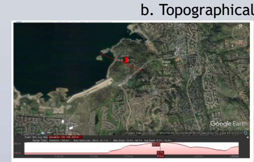
a. Radar Analysis



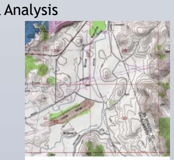
[Fig 10] Four radar velocity images at the time of tornadogenesis.

Rapidly intensifying mesocyclone evident as storm moves off Folsom Lake. [Fig 10]

b. Topographical Analysis



[Fig 11] The track and elevation profile of the of the Dec 24 2015 tornado producing mesocyclone



[Fig 12] USGS Topographical map of willow creek erosion channel.

Figures 11 and 12 show the perpendicular topographic channel that the mesocyclone encountered.

3. Image Analysis

[Fig 13] Evolution of tornado over 1.5 minutes

Over the span of 1.5 minutes, the condensation funnel has increased in length and become more defined. The actual wall cloud has become compacted. This is evidence of vorticity stretching in a short period of time. [Fig 10]

References -
http://bit.ly/NaikReferences

Acknowledgments -
M.R. Igel, UC Davis, AGU Fall Meeting, American Geophysical Union