# Atmospheric Rivers in Southwestern California and their Relationship to Operational Severe Weather and Flash Flood Forecasting

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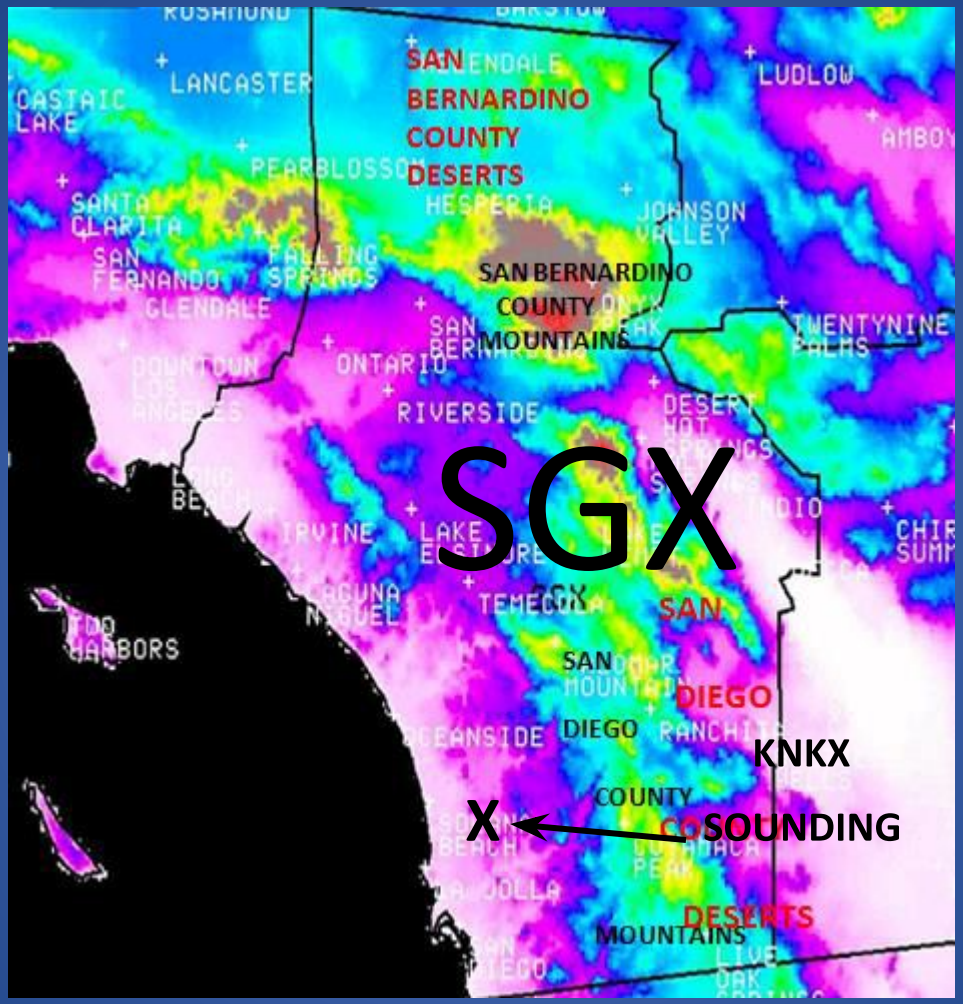
# INTRODUCTION

- Atmospheric Rivers are an occasional visitor to Southern California.
- When they do move in, they can produce locally heavy rain, and sometimes thunderstorms.
  - This can include large hail, damaging winds, and flash flooding.

# INTRODUCTION

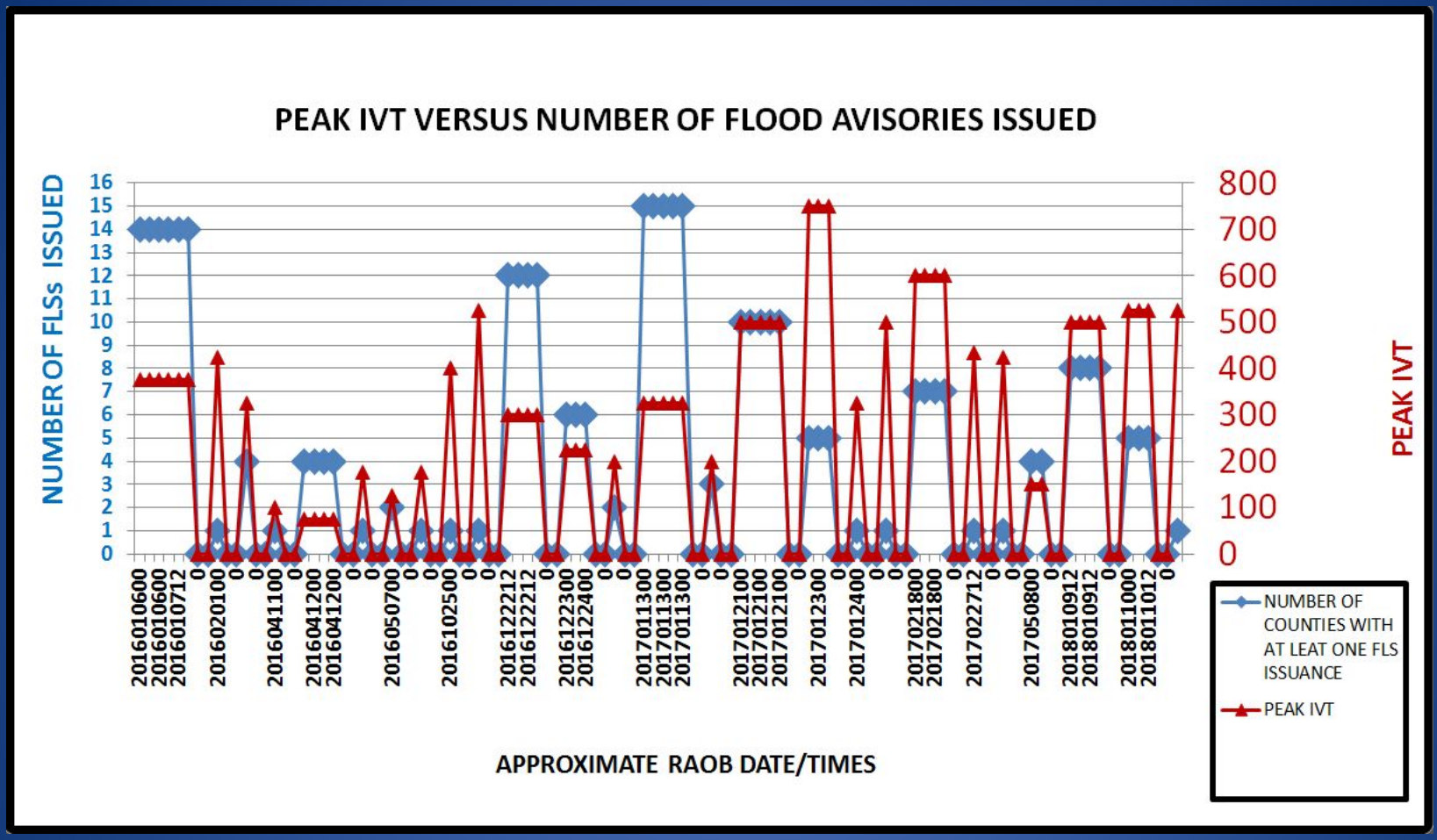



- The black outline on the map shows the land areas that are the responsibility of the NOAA/National Weather Service Office in San Diego (SGX)

# METHODOLOGY

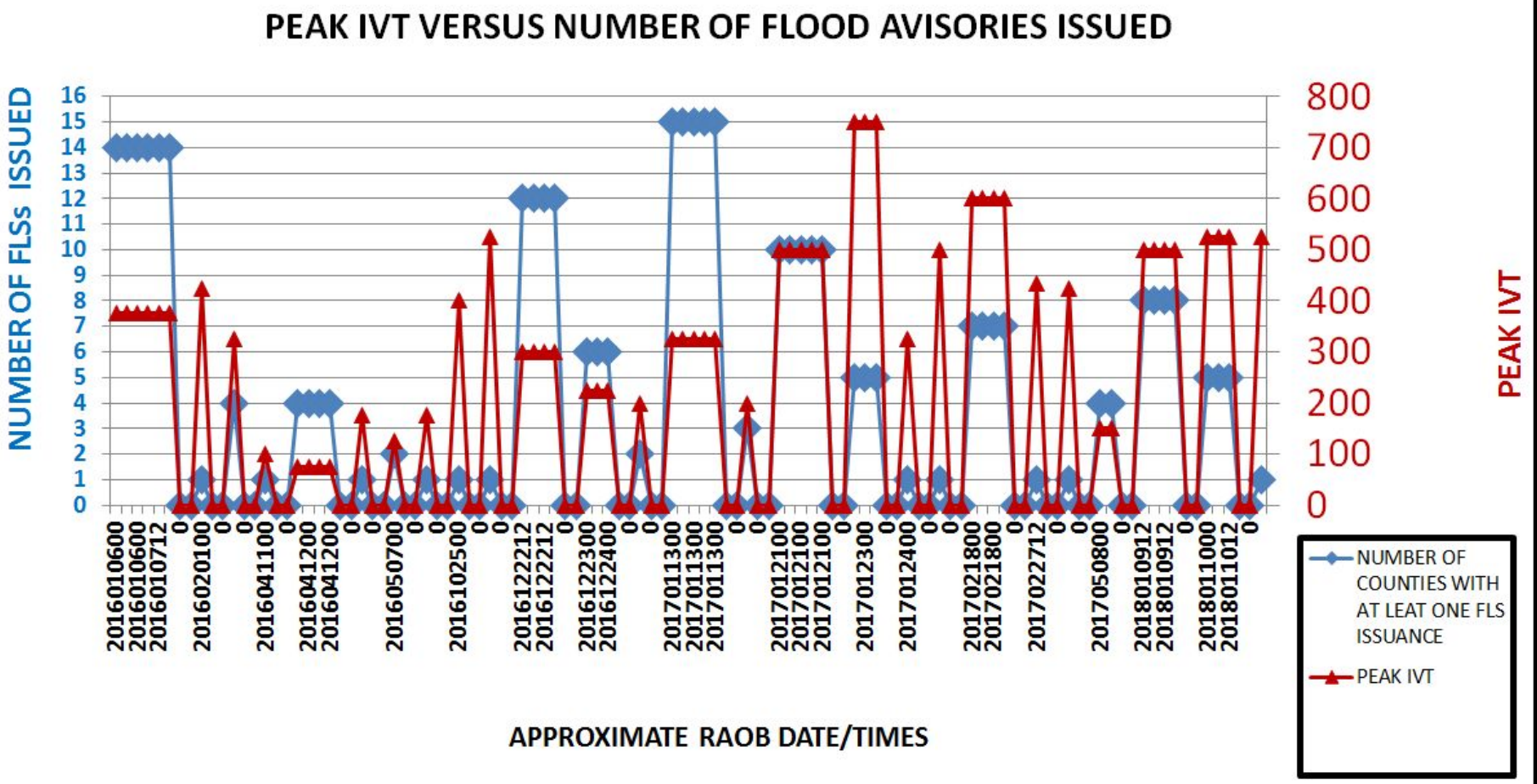
- The purpose of this presentation is to take a look at recent AR activity, the impacts, and also some explanation of what seem to be some of the driving factors behind the impacts.
- In order to investigate this,  I started with the events when flood advisories (advisories for nuisance flooding, otherwise called FLS issuances) occurred in the National Weather Service San Diego Forecast area.
- For those events, the peak IVT magnitude for the event was taken from the WR toolkit and shown on a graphic (Severe weather and flash flooding will be addressed in later charts).

# FLOOD ADVISORIES VERSUS AR AND "NEAR AR" EVENTS



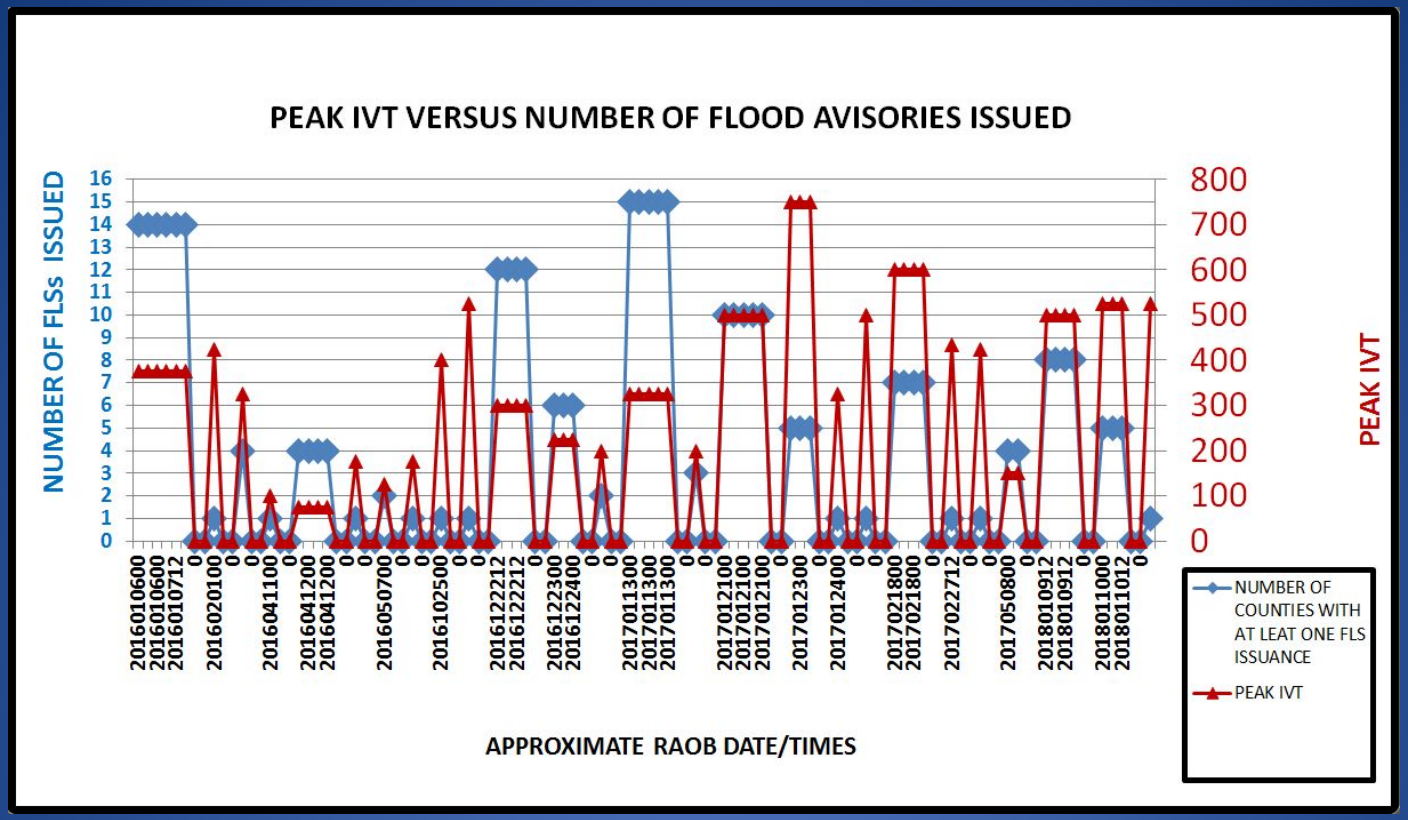

- The above graphic shows the days when flood advisories (FLS) were issued during the months of October – May and between 1/1/2016 and 5/31/2018.
- The top of the blue curves indicate the number of FLS events corresponding to an IVT peak, and uses the blue scale on the left-hand side of the graphic.
- The top of the red curves indicate the peak IVT for the event, and uses the red scale on the right-hand side of the graphic.

# FLOOD ADVISORIES VERSUS AR AND "NEAR AR" EVENTS




- Note that for the first event of 2016 the blue curve shows that for our county warning area, 14 FLSs were issued (some counties received multiple advisories), which peaked with an IVT magnitude based on the top of the red curve of about 375 kg $m^{-1}$ $s^{-1}$.

# ISSUED FLOOD ADVISORIES VERSUS AR EVENT PEAK

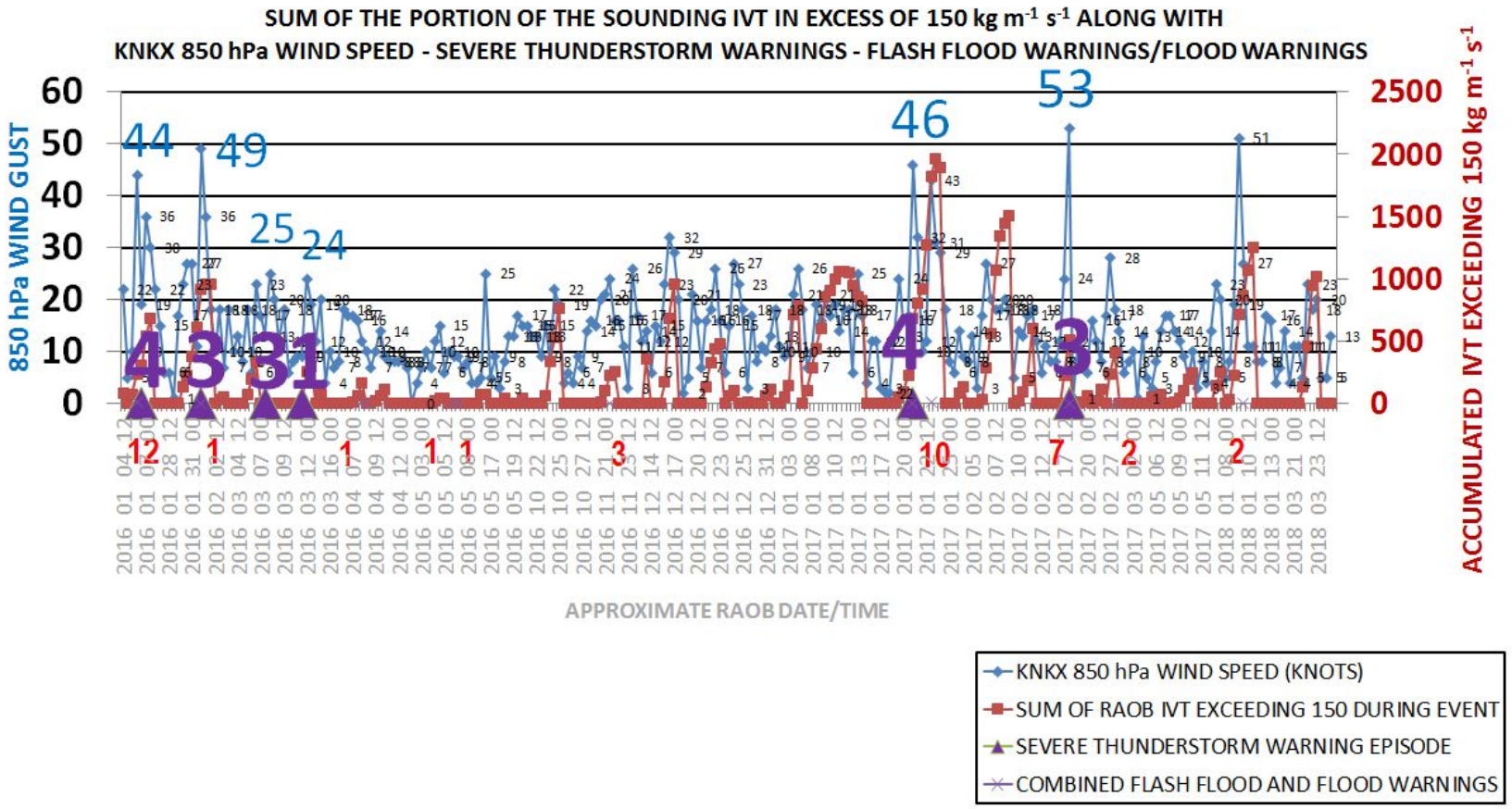



- Note that some of the FLS events are somewhat less than 250 ( “near AR level or sub-AR level events” ) with IVT peak values of 150-249.
  - Note that there were at least 4 FLS events around April /May 2016 with the IVT maxima less than 250.
    - Probably in part, due to having a strong enough blocking/difluence pattern and low level jet strength (low-level jet and/or blocking seems to be key, with significant moisture support supplementing the strength of these moisture flux episodes that lead to the heavy rain and subsequent flooding).
      - Of course the episodes should be inspected for slow/training cells as well.
  - The number of events associated with an episode had good correlation with peak IVT values.

# ACCUMULATED SIGNIFICANT IVT

- In a simple attempt to combine IVT magnitude with duration, an estimated IVT was created by taking the precipitable water (in inches), multiplying it by the 700 hPa wind speed (in knots), and multiplying it by 10 in order to create a very rough estimate of the IVT, or “approximated IVT”.
- This “approximated IVT” is then used to evaluate the amount of significant IVT on a sounding (IVT in excess of 150 on a sounding was considered to be “significant”)
- The amount of IVT on a sounding that exceeds 150 was combined with that of the next sounding, which accumulates with each sounding until the IVT of a sounding falls below 150.
  - For example, if the IVT of the first sounding is 200, the accumulation of significant IVT is 200-150 = 50 at that time.
  - If the second sounding , 12 hours later, reaches a value of 250, then its contribution to the storms “significant IVT” is 250-150 = 100, and the accumulated value for the storm is now 50 + 100 = 150.
  - This continues until the IVT for a sounding falls below 150, in which case the accumulated value falls back to 0 in preparation for the next event.

# SEVERE/FLASH FLOOD/FLOOD WARNING EVENTS




- This graphic takes this accumulated significant IVT, which is the sum of the significant IVT (IVT that exceeds 150 kg $m^{-1}$ $s^{-1}$ summed up), and compares it to the impact (severe thunderstorm warnings being issued, along with flash flood warnings and flood warnings combined, being issued).
- At least in this dataset, severe thunderstorm warnings (the purple numbers) were issued for almost every episode when 850 hPa winds reached the mid-40s or higher in knots (the large blue numbers). Note also the estimated IVT accumulation was typically 750 kg $m^{-1}$ $s^{-1}$ or higher.
- The red numbers near the x-axis are the combined number of FFWs and FLWs issued during an event.

# IVT-CATs AND WFO SGX ADVISORY/WARNING IMPACTS

ESTIMATED IVT CATEGORY VERSUS IMPACT ON ADVISORY/WARNING ISSUANCES AND PERCENTAGE OF DAYS AN ISSUANCE OCURRED (OCTOBER-MAY, 1/2016-5/2018)

| | 0-23 HOURS | 24-47 HOURS | 48-71 HOURS | 72 HOURS AND OVER |
|---|---|---|---|---|
| EXCEPTIONAL<br>1250 OR MORE | | | | |
| EXTREME<br>1000-1149 | | | | |
| STRONG<br>750-999 | | | | |
| MODERATE<br>500-749 | | 20160218 508/24 NONE<br>20161216 664/36 1 FLS<br>20170211 566/24 NONE<br><br>FLS – 1/3 (33%)<br>FFW AND FLW- 0/3 (0%)<br>SVR - 0/3 (0%) | 20170207 654/48 1 FLS<br>20180109 637/60 14 FLS 2 FFW<br>20180408 502/48 NONE<br><br>FLS – 2/3 (66%)<br>FFW AND FLW – 1/3 (33%)<br>SVR – 0/3 (0%) | 20170122 609/84 19 FLS 10 FFW 4 SVR<br><br>FLS – 1/1 (100%)<br>FFW AND FLW – 1/1 (100%)<br>SVR – 1/1 (100%) |
| WEAK<br>250-499 | 20160119 297/12 NONE<br>20160120 272/12 NONE<br>20160124 263/12 NONE<br>20160130 281/12 NONE<br>20160322 326/12 NONE<br>20160501 300/12 NONE<br>20161121 272/12 1 FFW<br>20161127 303/12 NONE<br>20170113 304/12 15 FLS<br>20170306 301/12 NONE<br>20170331 270/12 NONE<br>20170408 396/12 NONE<br>20171020 362/12 NONE<br>20171021 285/12 NONE<br>20171116 250/12 NONE<br>20171121 324/12 NONE<br>20171221 260/12 NONE<br>20180412 257/12 NONE<br>20180417 252/12 NONE<br>20180525 281/12 NONE<br><br>FLS - 1/20 (5%)<br>FFW AND FLW - 1/20 (5%)<br>SVR - 0/20 (0%) | 20160106 380/24 12 FFW 4 SVR<br>20160111 298/24 NONE<br>20160116 399/24 NONE<br>20160201 457/36 1 FLS 1 FFW 3 SVR<br>20160306 263/12 NONE<br>20160306 297/24 3 SVR<br>20160312 405/24 4 FLS 1 SVR<br>20161024 421/36 1 FLS<br>20161128 415/36 NONE<br>20161211 329/24 NONE<br>20161222 343/36 14 FLS<br>20170106 432/36 NONE<br>20170111 331/24 NONE<br>20170218 438/24 7 FLS 3 SVR 5 FFW FLW 2<br>20170227 382/24 2 FLS<br>20170322 329/24 NONE<br>20170419 285/24 NONE<br>20170425 442/36 NONE<br>20171117 365/24 NONE<br>20180107 292/24 NONE<br>20180323 633/36 1 FLS<br><br>FLS - 7/21 (33%)<br>FFW AND FLW - 3/21 (14%)<br>SVR - 4/21 (19%) | 20170109 351/60 NONE<br>20170428 429/48 NONE<br>20171107 337/60 NONE<br>20180310 381/48 NONE<br><br>FLS - 0/4 (0%)<br>FFW AND FLW - 0/4 (0%)<br>SVR - 0/4 (0%) | |
| NON-AR<br>0-249 | 20160408 247/00 1 FLS<br>20160504 177/00 4 FLS<br>20160507 108/00 1 FFW<br>20160518 197/00 1 FLS<br>20161011 202/00 1 FLS<br>20161231 210/00 1 FLS<br>20170510 210/00 4 FLS | | | |

NATIONAL WEATHER SERVICE SAN DIEGO FORECAST AREA FLOOD ADVISORIES, FLASH FLOOD/FLOOD WARNINGS, SEVERE WEATHER EVENTS AND ASSOCIATED IVT CATEGORIZED BY IVT PEAK AND DURATION (DURATION USED WAS 250 kg $m^{-1}$ $s^{-1}$ OR MORE FOR CONSECUTIVE KNKX SOUNDINGS AT 12 HOUR INTERVALS). THE BOXES CONTAIN THE GMT DATE, MAX IVT, DURATION, AND WHETHER OR NOT AN FLS, FFW/FLW, OR SVR WAS ISSUED. NON-AR LEVEL ACTIVITY IS IN THE NON-AR/0-23 HOUR BOX FOR FLOOD ADVISORIES ISSUED, BUT IVT WAS BELOW 250 kg $m^{-1}$ $s^{-1}$ (FOR COMPARISON). MAX IVT WAS ESTIMATED FROM THE KNKX SOUNDING USING THE FORMULA IVT = PW IN INCHES X 700 hPa WIND SPEED IN KNOTS X 10 FOR SIMPLICITY. A LARGER DATASET WOULD MAKE THE "PERCENTAGES OF DAYS THAT ISSUANCES OCCURRED" VALUES MORE REPRESENTATIVE.

- Explanation of the above chart concerning categories (basic format of the chart from Ralph et al…) will be shown in the following slide.
- Red highlighted text indicates that either flood or severe products were issued around that time.

# IVT-CATs AND WFO SGX ADVISORY/WARNING IMPACTS

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- From the bottom of the above IVT peak magnitude/duration table…
  - National Weather Service San Diego Forecast area flood advisories, combined flash flood warnings and flood warnings, severe thunderstorm warnings, and associated IVT maxima for the events are categorized by IVT peak and duration in the table.
  - Duration used was 250 kg $m^{-1}$ $s^{-1}$ or more for consecutive KNKX soundings at 12 hour intervals.
  - The boxes contain the GMT date, max IVT, duration of IVT values 250 or greater, and whether or not an FLS, FFW/FLW, or SVR was issued.
  - Non AR Level activity is in the non-AR/0-23 hour box for products issued, but IVT was below 250 kg $m^{-1}$ $s^{-1}$ (for comparison, in orange).
  - Max IVT was estimated using the KNKX sounding, and using the formula IVT = PW in inches x 700 hPa wind speed in knots x 10 for simplicity.

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- Note that events almost follow the diagonal in the chart (weaker events are shorter, and larger IVT events last longer).
- Mainly nothing happened in the lower left (250-499 peak IVT and 0-23 hours) with an FLS and a FFW only, and "basically everything" happened for conditions in the upper right (500-749 peak IVT and 72 hours or longer category) with numerous warnings for both severe weather and flash flooding.

# IVT-CATs AND WFO SGX ADVISORY/WARNING IMPACTS

- It should be mentioned that there was a large AR in early April 2018, with an estimated peak IVT of 502 and IVT in excess of 250 kg $m^{-1}$ $s^{-1}$ for about 48 hours, but the lack of blocking, low-level jet support, and associated difluence probably reduced the likelihood of FLS/FFW/FLW/SVR issuances.

# SEVERE WEATHER

- The most significant severe wind gust events were associated with very strong 850 hPa winds (and to some extent, 700 hPa winds were also rather strong).
- The 850 hPa wind speeds, which have a tendency to surface along the coast as surface wind gusts, can easily be closer to 1 ½ times the 850 hPa winds, especially when stronger cells/NCFR/Line segments move in with radar returns of around 50 dBZ or more.
- Over approximately the past 10 years, the top few events had 850 hPa wind speed Standardized Anomalies of about 4-6, which puts them around 45-55 knots.
  - Most of the severe wind gust days consisted of multiple severe thunderstorm warnings, mainly involving issuance, then re-issuance of warnings for long lived cells or lines of cells (strong NCFRs or NCFRs moving in as small segments of a cold front were notorious for this).
  - It was not unusual to <u>not</u> have any lightning, and still produce severe level damage, even with surface wind gusts of only 45-55 mph, especially in areas that don't often see such strong, gusty southwest to west winds (for example, the coastal areas).
    - Partly due to the infrequency of strong onshore wind events. When they do occur, they blow down weak/diseased trees and large branches that fall on powerlines. This can also be due to saturated soils.

# SEVERE WEATHER

- Cool season large hail events are quite rare, and there were none in this dataset (October – May of 2016, 2017,and 2018), so severe thunderstorm events were damaging wind gust types of events as is typical with cool season AR events in Southern California.

# OTHER AR-RELATED WIND ISSUES

- Such strong 850 hPa winds can also be a reflection of what is occurring further aloft, for example, the 700 hPa winds, when strong Atmospheric Rivers move in.
  - The ARs can affect mountain/desert slopes since winds approach high wind warning criteria (and some wind damage in those areas can occur) when 700 hPa winds approaching the mountains are around 45-50 knots, and rather easily result in high wind warnings and wind damage with winds at that level reaching 50 knots or higher based on some of the past events (of course, evaluated along with other parameters).
  - Sometimes, the 850 hPa winds can be nearly as strong (or even stronger) than the 700 hPa winds, then the mountain/desert slopes can receive wind gusts approaching 2 X the 850 hPa wind speed approaching the area.
    - This adds further issues to consider during warning/forecast operations when deciding on the appropriate decision support activities for an event.

# CONCLUSIONS

- The IVT-CATs table format does seem to do a fine job in categorizing the character of the event based on the estimated IVT for the October – May period of 2016, 2017, and 2018 when products such as warnings and advisories are indicated in the table.
  - Placing the actual events into the table format localizes the impacts to the forecast area involved (although more data is needed than is shown in this preliminary dataset in the future to more accurately reflect the impacts).
  - Some investigations by others have used storm data reports in a similar fashion.
- It is indicative of the potential workloads for operational warning/ forecasting, and also reflects upcoming decision support potential, so such a table should prove very useful to both avenues in a WFO.
- A summation of the "significant IVT" (the IVT in excess of 150 kg $m^{-1}$ $s^{-1}$ or 250 kg $m^{-1}$ $s^{-1}$ ) may be a useful way to combine the IVT and duration into one parameter, and allow useful charts and graphics to be developed with other parameters such as "accumulated IVT versus instability" and "accumulated IVT versus wind or max wind gusts, which will be investigated in the future.
- Standardized anomalies will also be looked into for such graphics and tables.

# THE END