ATMOSPHERIC RIVERS AND ENHANCED INTEGRATED VAPOR TRANSPORT EPISODES: THEIR ROLE IN DAMAGING FRONTAL PASSAGES IN SOUTHERN CALIFORNIA WITH AN EMPHASIS ON STRONG WINDS

2016 INTERNATIONAL ATMOSPHERIC RIVERS CONFERENCE
SAN DIEGO, CA
8-11 August 2016

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- 10 August 2016

INTRODUCTION

Map of Southern California

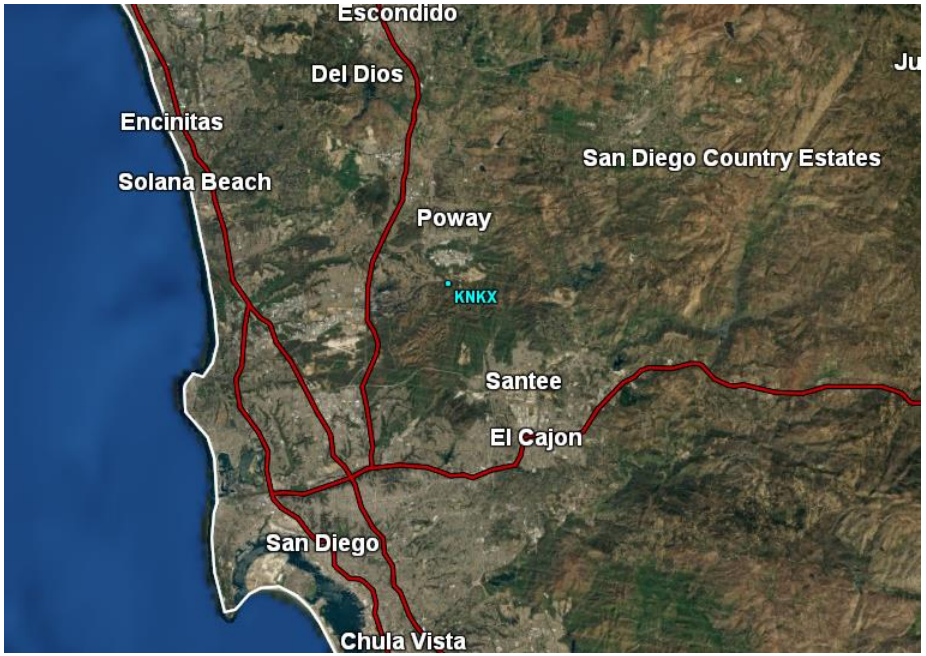
- Atmospheric rivers (e.g., *Zhu and Newell 1998; Ralph et al. 2004;)* are not infrequent visitors to the west coast, but they only occasionally slip far enough south to affect Southern California
- The main impact is typically heavy rain, but another significant impact is strong winds and severe weather

INTRODUCTION

Map showing the locations of the Santa Ana Radar (KSOX) and the Miramar Radar (KNKX)

•Integrated water vapor transport (IVT), consisting of strong winds and enhanced moisture, combined with instability can generate damaging frontal passages

INTRODUCTION



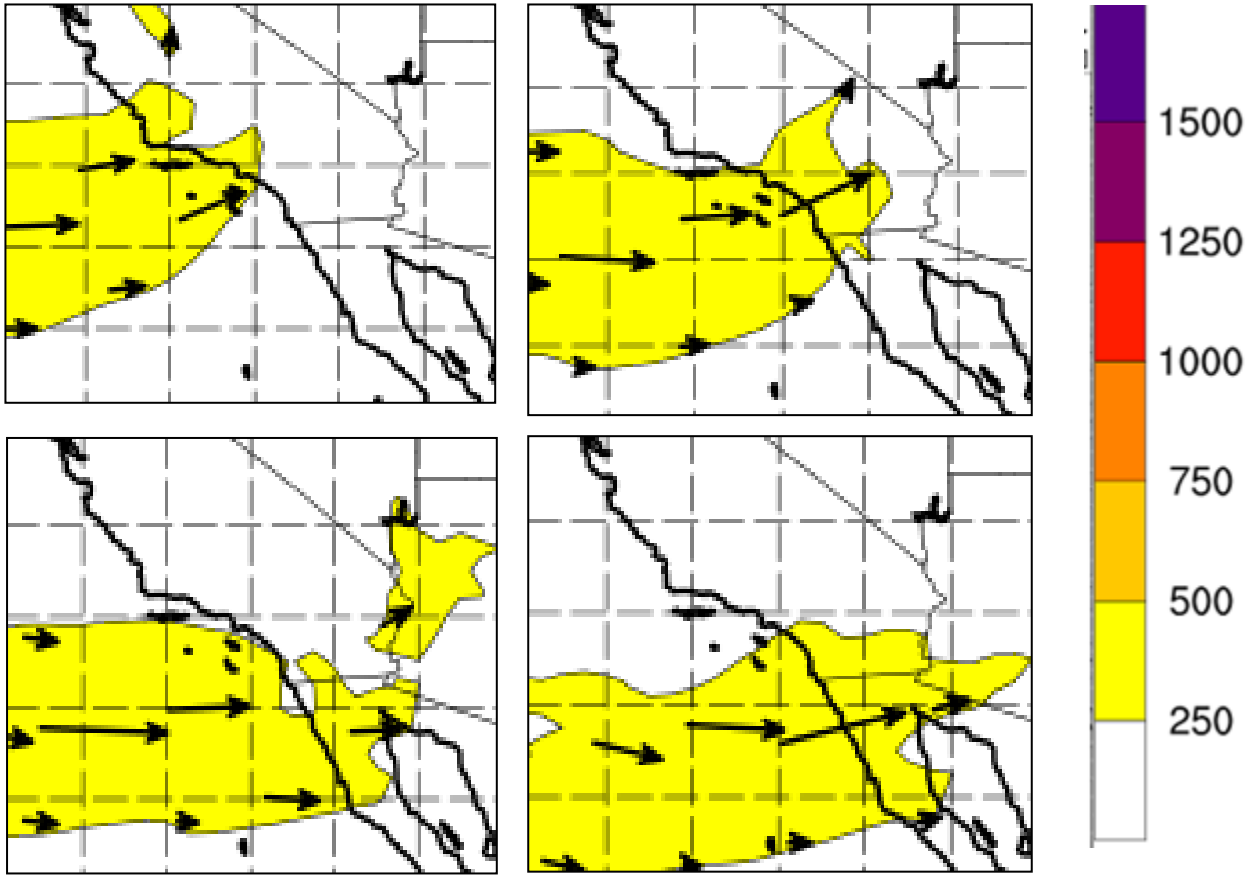
Maps of Southern California in the vicinity of the Santa Ana Radar (KSOX) and the Miramar Radar (KNKX)

- Commerce impacts, (such as low ceilings/visibilities, wind shear, hail, and lightning for aviation, along with utility company issues such as downed trees and power lines) are also concerns.
- The main purpose of this study is to make some brief comparisons of IVT to damaging impacts in the region and show some results as well for the recent cool season (2015-2016).

INTRODUCTION

- The events analyzed that were damaging basically had the characteristics of severe/damaging weather events of this type that occur in Southern California
  - Strong negatively-tilted trough
  - Above average to extreme low level winds compared to normal
    - Strong low level flow [about 25 kt + (or about 12.5 $m^{-1} s^{-1}$ +) near 850 hPa, and around 30 kt (15 $m^{-1} s^{-1}$ +) on radar about 2500 feet MSL (about 0.76 km) or lower].
      - During the 1/31-2/1 2016 case, 850 hPa winds were nearly 50 knots (25 $m^{-1} s^{-1}$). Radar data also showed strong winds surfacing with this event.
- Not all of the convective wind damage cases had 50 + dBZ radar returns accompanying them (and some far less), so both low level flow and 50 dBZ returns need to be scrutinized.
- All episodes of Atmospheric River Intrusions of IVT magnitudes ≥250 kg $m^{-1} s^{-1}$ that extended inland from the Pacific were examined and their impacts for the 1 January 2016 through 31 May 2016 period will be shown (Data courtesy of J. Cordeira).
  - It should be noted that the dataset is rather small since only a 5 month period was investigated.
- The inspection of IVT magnitudes ≥250 kg $m^{-1} s^{-1}$ was an easy threshold to select as most events appeared to be associated with IVT magnitudes of about 250-500 kg $m^{-1} s^{-}$ moving inland over the WFO San Diego Forecast Area during the period investigated.

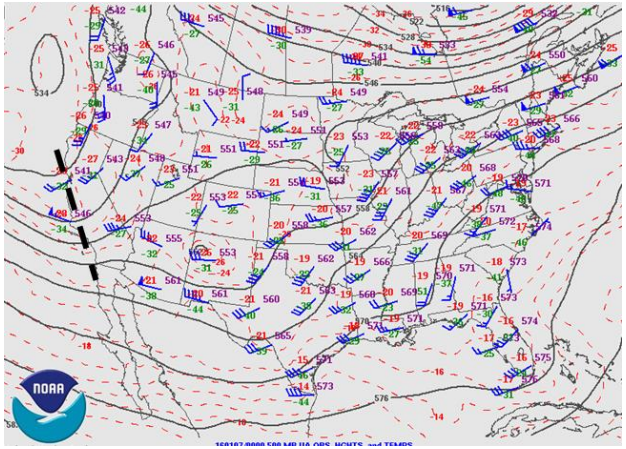
6-7 January 2016

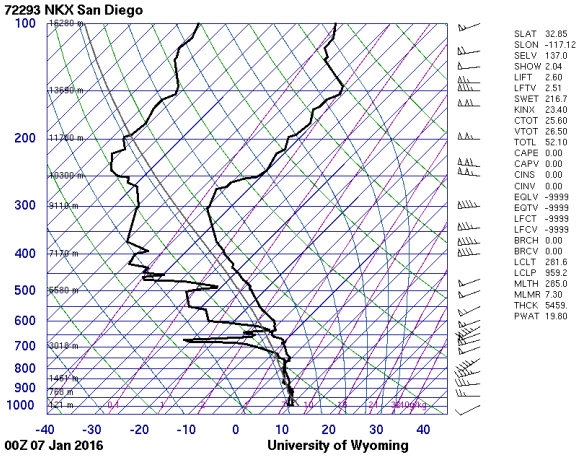


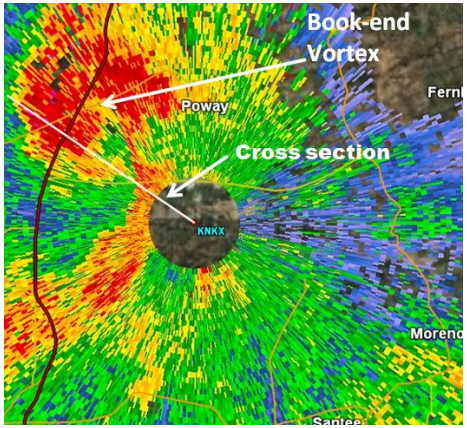
The above images are the NCEP GFS IVT (kg m^{-1} s^{-1}) and IVT Vector initialized and valid at 1800 UTC 6 January 2016 (upper left), 0000 UTC 7 January 2016 (upper right) , 0600 UTC 7 January 2016 (lower left), and 1200 UTC 7 January 2016 (lower right).

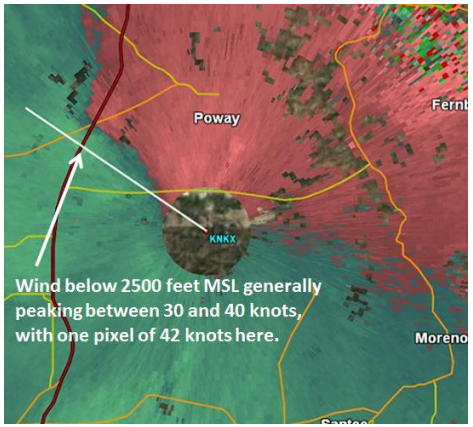
- Notice that IVT magnitudes ≥250 kg m^{-1} s^{-1} moves over Southern California and extends inland.

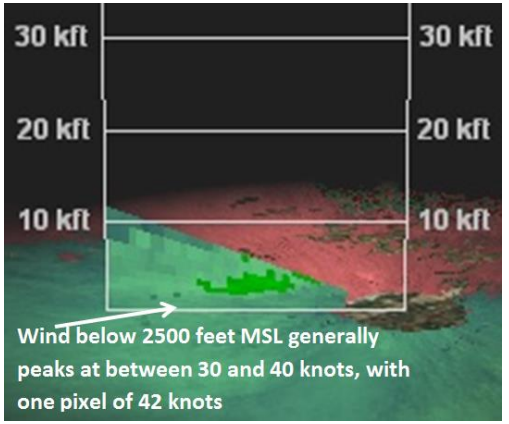
6-7 January 2016 - continued

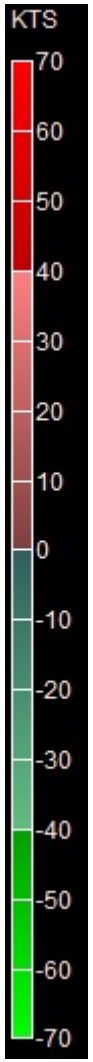








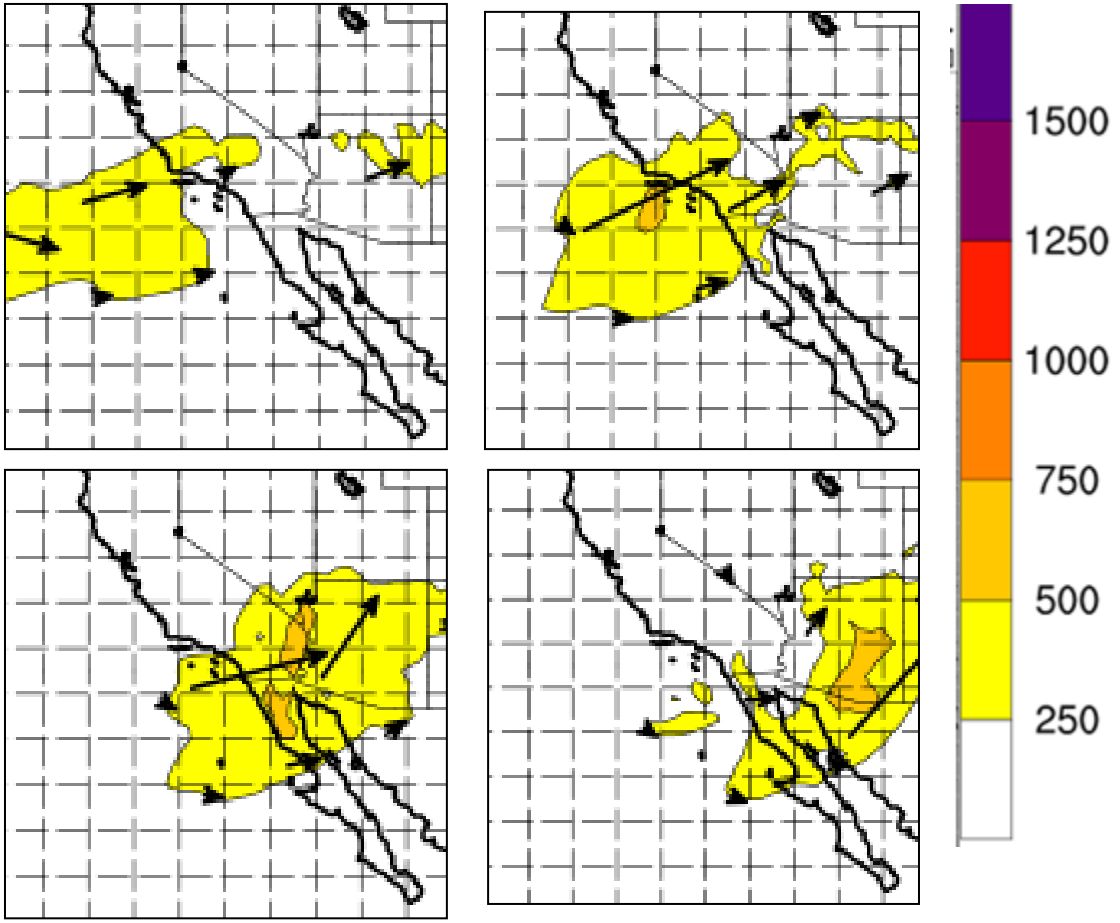




The upper images are the 500 hPa heights at 0000 UTC 7 January 2016 (upper left) and KNKX sounding (upper right). The lower images are the KNKX radar 0.5 degree base reflectivity (lower left), 0.5 degree base velocity (lower middle) and the corresponding cross section (lower right) at 2313 UTC 6 January 2016.

- The 500 hPa chart and sounding show a negative tilt trough and well over 25 knot winds (12.5 $m^{-1} s^{-1}$) at 850 hPa, and in this case it was actually around 35 knots (17.5 $m^{-1} s^{-1}$).
- Storm data reported an estimated 48 knot (24 $m^{-1} s^{-1}$) wind gust in the Poway area.
- Radar winds [using GR2Analyst software (2013)] peaked around 42 knots (21 $m^{-1} s^{-1}$) at 1170 feet MSL (which is in the 2500 feet MSL and lower category), with great structure (a bookend vortex was involved) for numerous trees down in Poway. A side note is that the radar may not be seeing the strongest winds, which may be perpendicular to the beam.

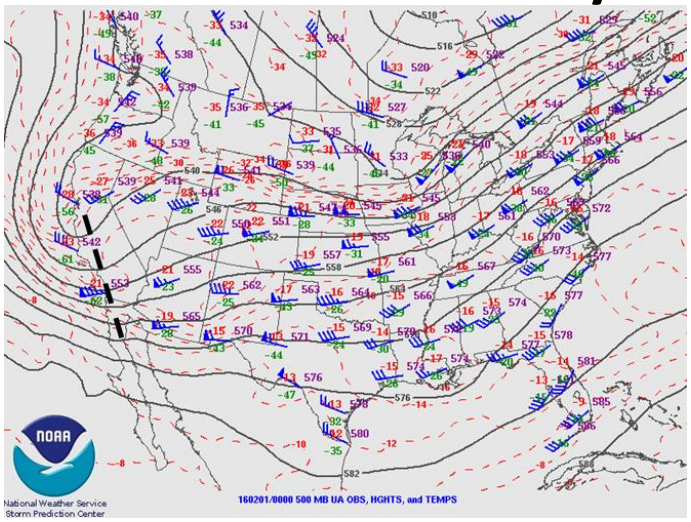
31 January - 1 February 2016

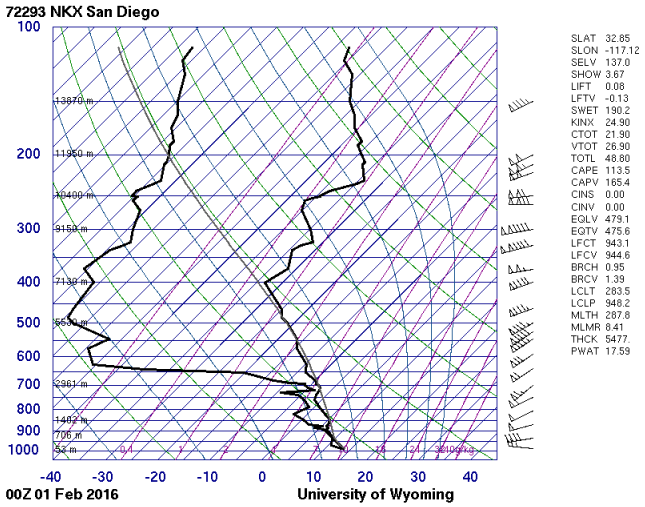


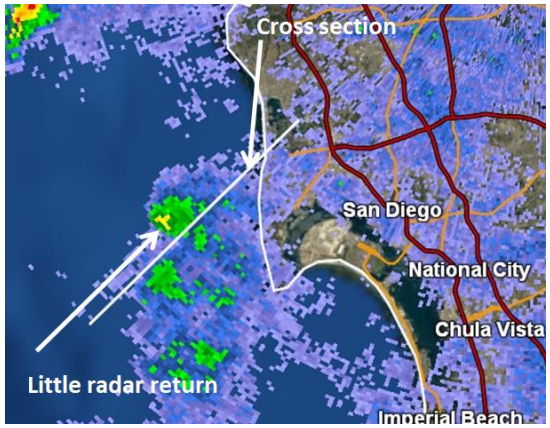
NCEP GFS IVT (kg m^{-1} s^{-1}) and IVT Vector initialized and valid at 1200 UTC 31 January 2016 (upper left), 1800 UTC 31 January 2016 (upper right), 0000 UTC 1 February 2016 (lower left) and 0600 UTC 1 February 2016 (lower right).

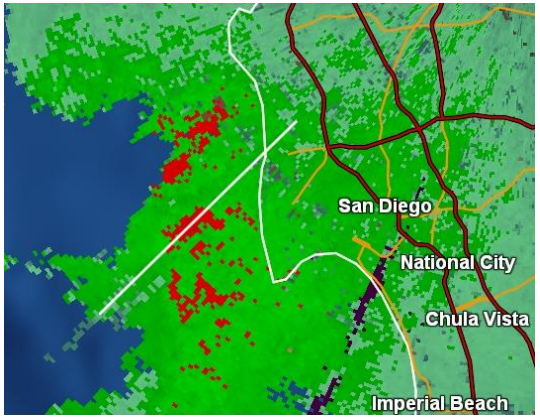
- Notice that IVT magnitudes ≥250 kg m^{-1} s^{-1} moves toward Southern California, but strengthens or maintains its core IVT magnitudes ≥500 kg m^{-1} s^{-1} at the Mexican Border and in the deserts, indicating a very strong event.

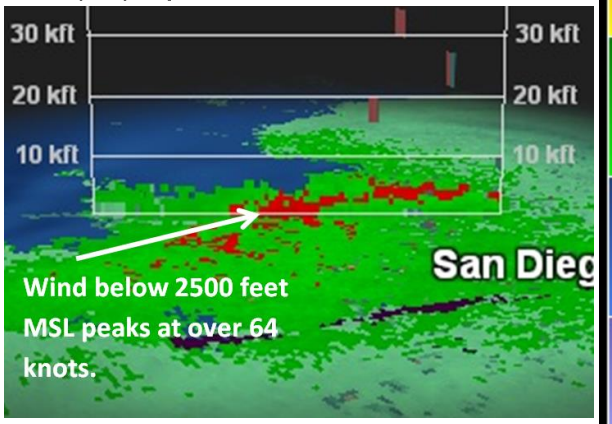
31 January - 1 February 2016 - continued

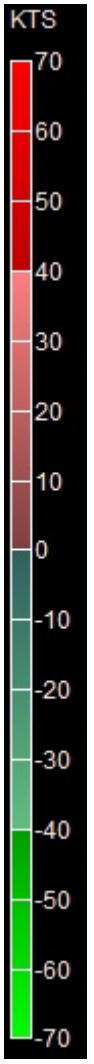








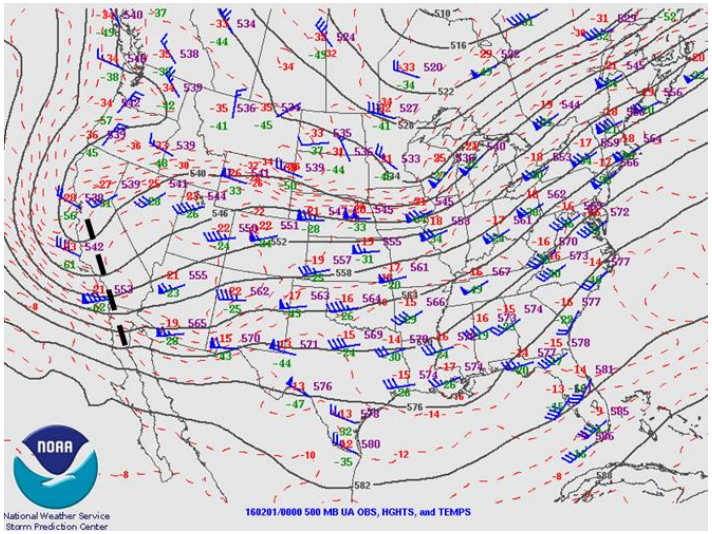


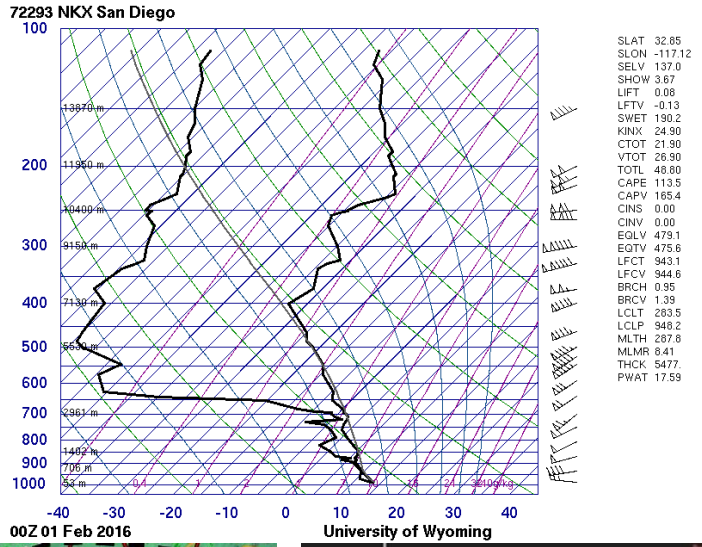


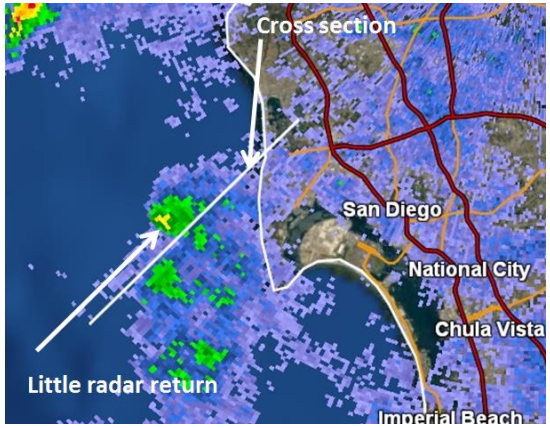
The upper images are the 500 hPa heights at 0000 UTC 1 February (upper left) and the 0000 UTC 1 February KNKX sounding (upper right). The lower images are the KNKX 0.5 degree base reflectivity (lower left), 0.5 degree base velocity (lower, middle) and velocity cross section (lower right) at 2232 UTC 31 January 2016.

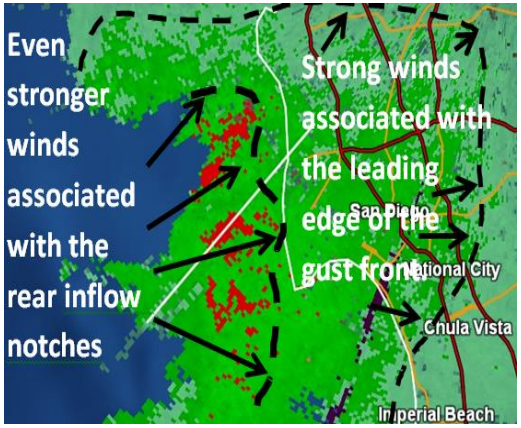
- This is a very dynamic event with a negatively-tilted trough and 49 knot 850 hPa winds on the sounding.
- Radar wind speed estimates [at 2500 feet MSL (0.76 km) and lower] of over 60 knots occurred with this event.
- These "aliased" (red) velocities are left in to more easily "draw the eye" to the very strong winds. Of course, one can "de-alias" the velocities to get the actual speed estimates, but a potential advantage of also looking at the "aliased" data is the red inflow notches show up well in the lower middle radar image and the cross section in the lower right image.

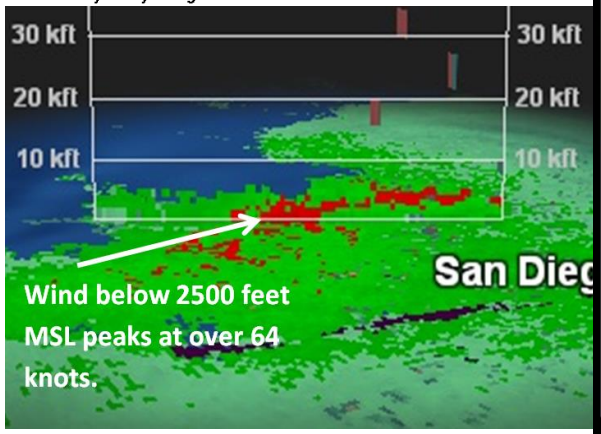
31 January - 1 February 2016 - continued

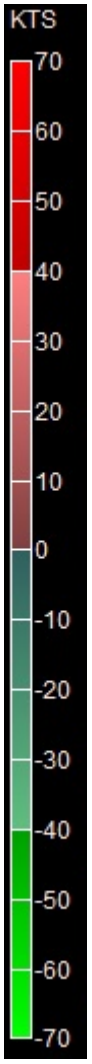








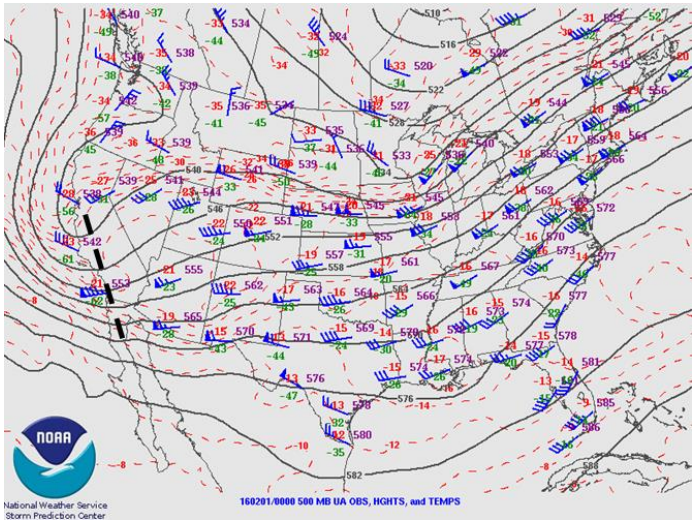


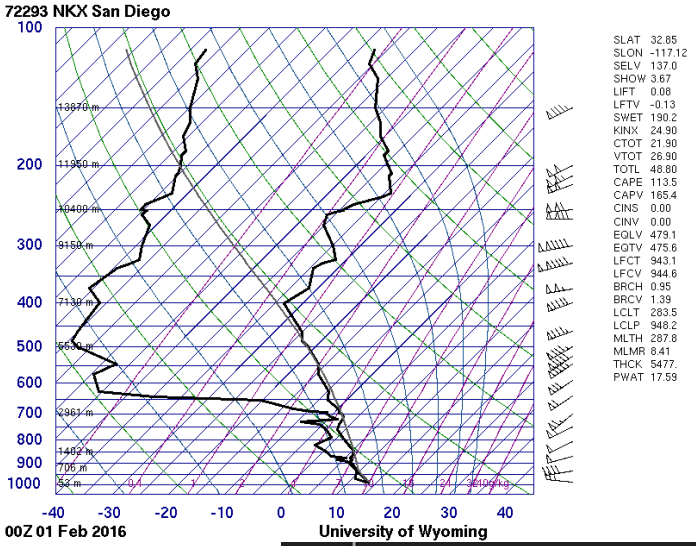


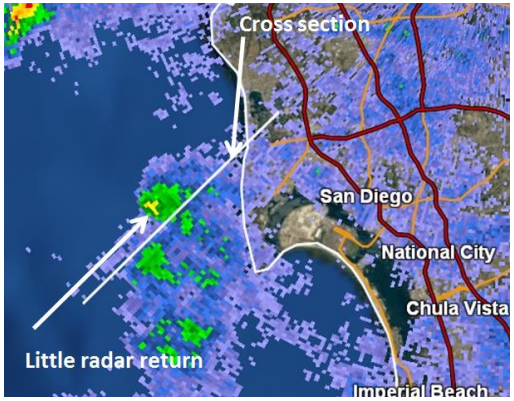
The upper images are the 500 hPa heights at 0000 UTC 1 February (upper left) and the 0000 UTC 1 February KNKX sounding (upper right). The lower images are the KNKX 0.5 degree base reflectivity (lower left), 0.5 degree base velocity (lower, middle) and velocity cross section (lower right) at 2232 UTC 31 January 2016.

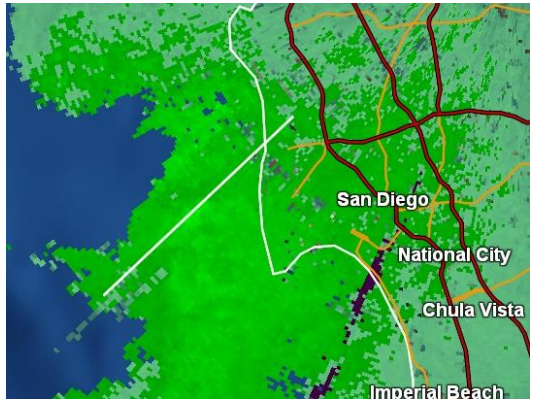
- The pattern of the aliased winds (red) in the cross section show the strong winds of the rear-inflow notches appearing at the back edge of arching, higher velocities that extend to the east and generally slant upward.
- Meanwhile, the initial outflow can be seen just east of San Diego near the leading edge of the strong low-level flow that transitions to the darker greens, (well ahead of the even stronger winds associated with the rear-inflow notches where it transitions to red).

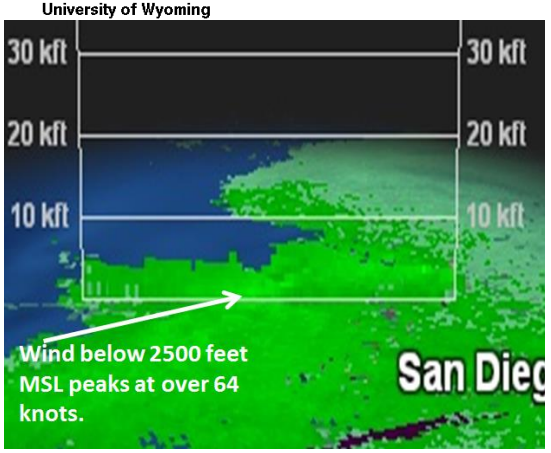
31 January - 1 February 2016 - continued

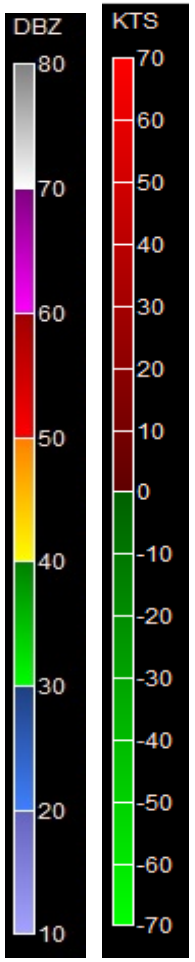








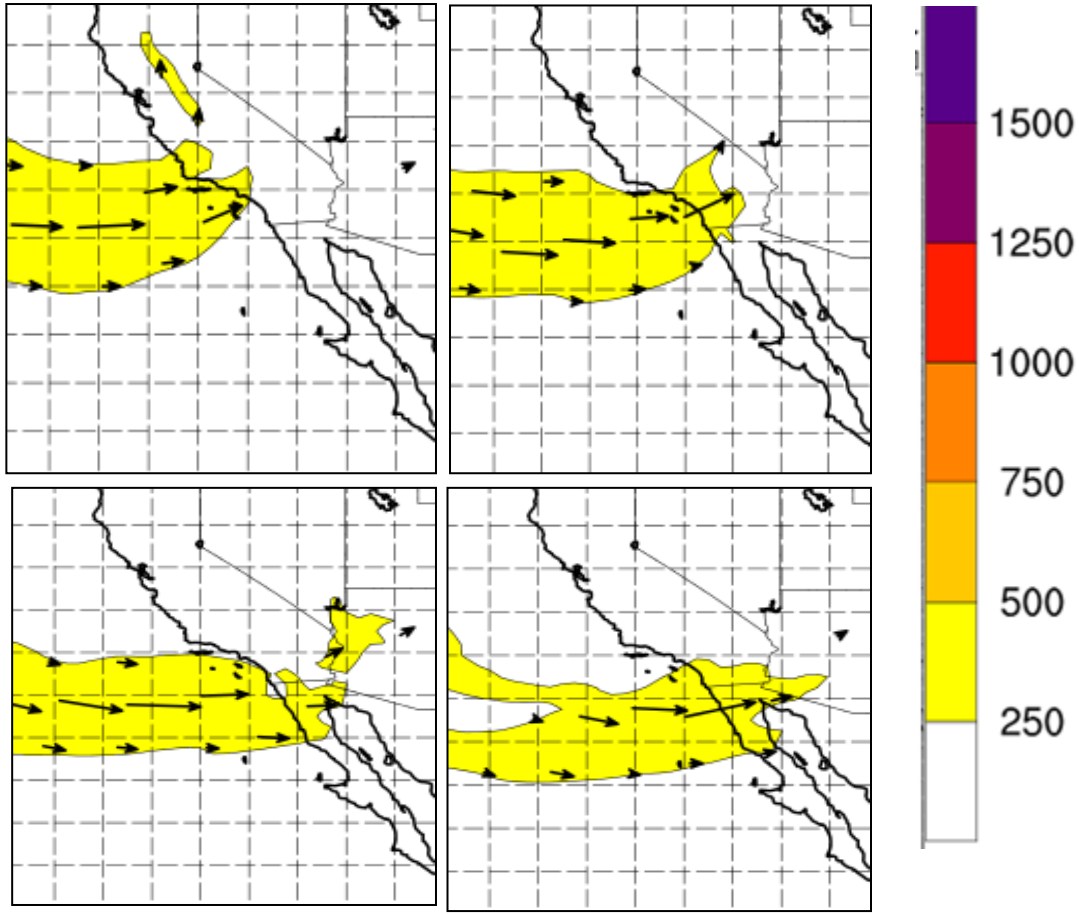




The upper images are the 500 hPa heights at 0000 UTC 1 February (upper left) and the 0000 UTC 1 February KNKX sounding (upper right). The lower images are the KNKX 0.5 degree base reflectivity (lower left), 0.5 degree base velocity (lower, middle) and velocity cross section (lower right) at 2232 UTC 31 January 2016.

- Here, the velocity data is "de-aliased" in order to get the speed estimates. The peak radar estimated speeds at 2500 feet MSL (0.76 km) or lower were in excess of 65 knots (32.5 $m^{-1} s^{-1}$).
- Numerous trees and even power poles were blown down, and there was 1 fatality when a large tree fell on an occupied vehicle in the San Diego area.

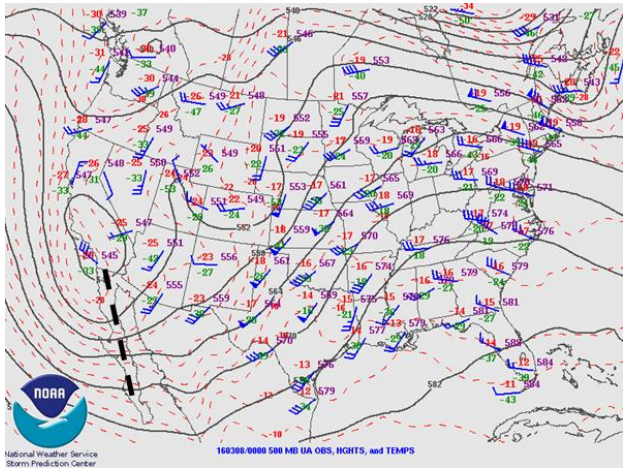
7 March 2016

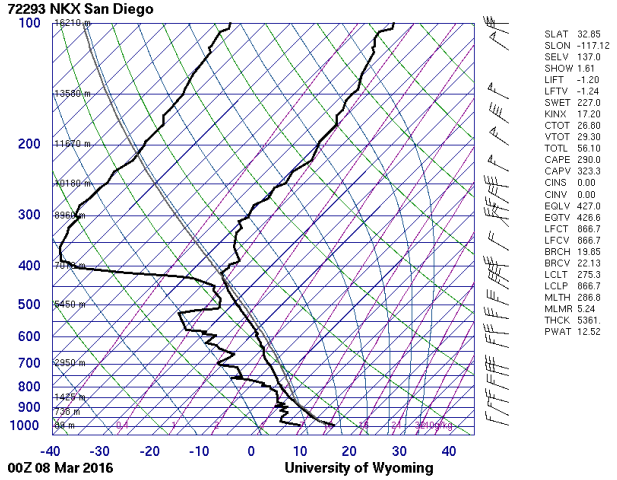


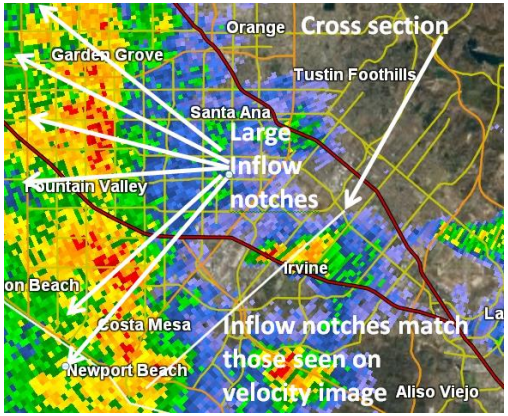
NCEP GFS IVT (kg m^{-1} s^{-1}) and IVT Vector initialized and valid at 1800 UTC 6 March 2016 (upper left) , 0000 UTC 7 March 2016 (upper right) , 0600 UTC 7 March 2016 (lower left) and 1200 UTC 7 March 2016 (lower right)

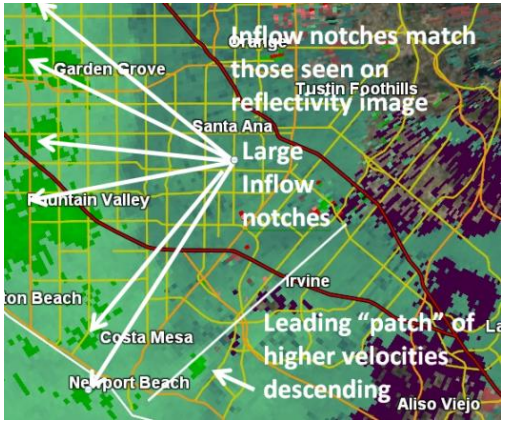
- Note that the intensity is indicating IVT magnitudes ≥250 kg m^{-1} s^{-1} but does not reach the IVT magnitudes ≥500 kg m^{-1} s^{-1} level.

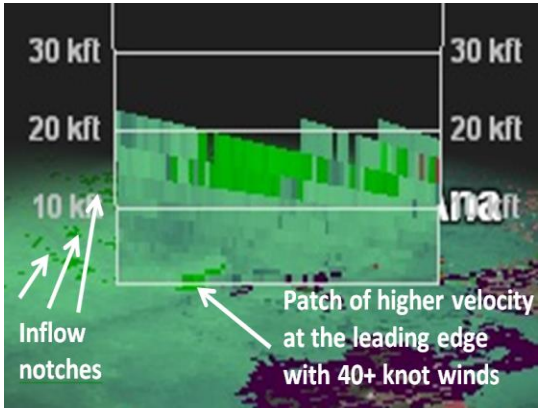
7 March 2016 - continued

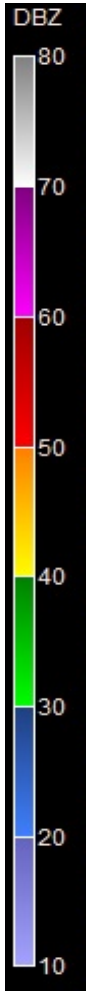


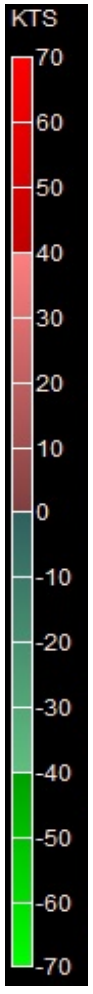










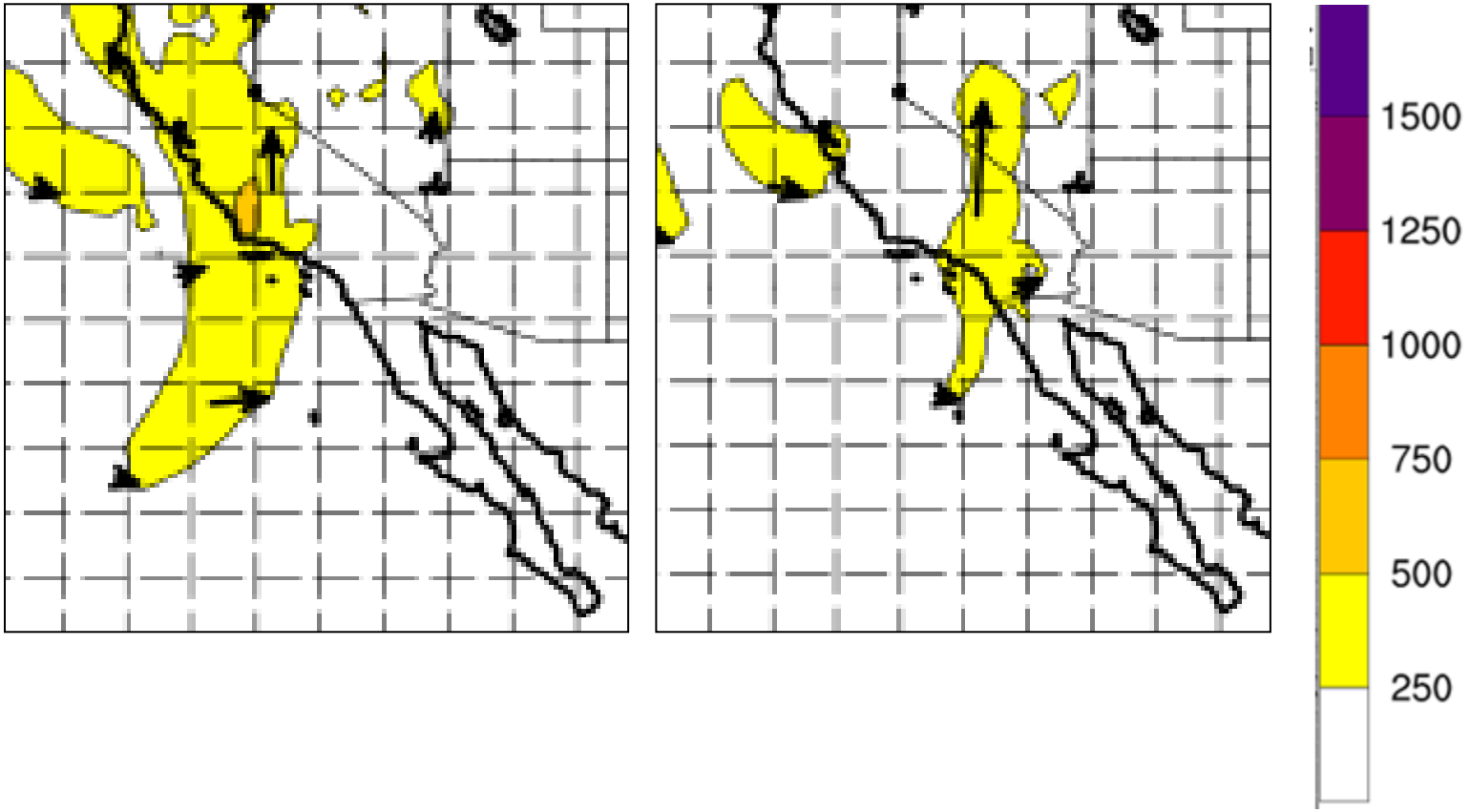


The upper images are the 500 hPa heights at 0000 UTC 8 March 2016 (upper left) and the 0000 UTC 8 March 2016 KNKX sounding (upper right). The lower images are the KNKX Radar 0.5 degree base reflectivity (lower left), 0.5 degree base velocity (lower, middle) and velocity cross section (lower right) at 1454 UTC 7 March 2016.

- There is a negatively tilted trough with 25 knot (12.5 $m^{-1} s^{-1}$) 850 hPa winds
- Note the numerous arrows indicating the inflow notches near the main band
- Downed trees were reported with surface winds gusting to around 43 knots (21.5 $m^{-1} s^{-1}$) in the Irvine area
- Note the couple of cells near the leading edge of the gust front well ahead of the main band and larger inflow notches.

Lastly, the KSOX radar is at 3106 feet MSL (0.9 km) so the beam is well above ground level (above 2500 feet MSL).

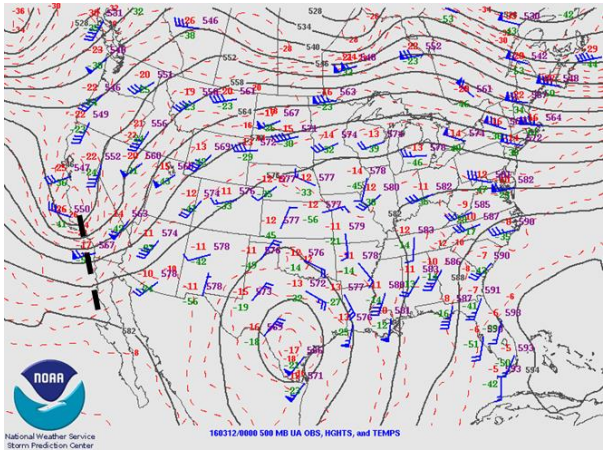
11-12 March 2016

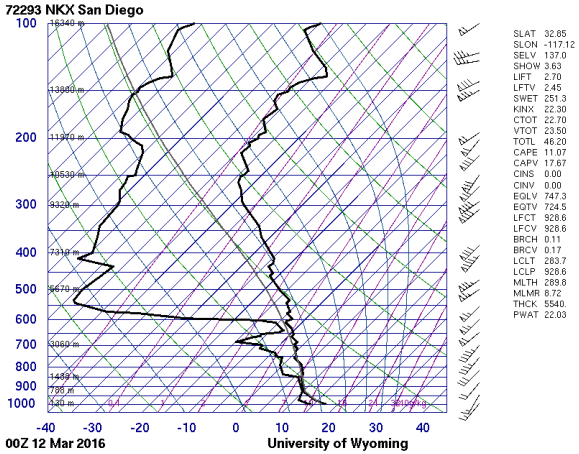


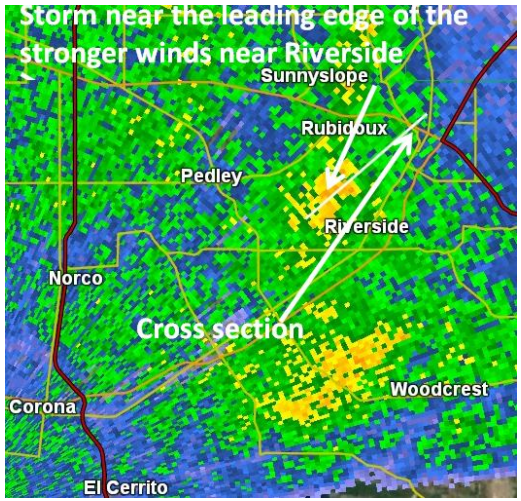
NCEP GFS IVT (kg m^{-1} s^{-1}) and IVT Vector initialized and valid at 1800 UTC 11 March 2016 (left and 0000 UTC 12 March 2016 (right) . Notice that the IVT250-499 moves toward Southern California, but weakens as it moves in.

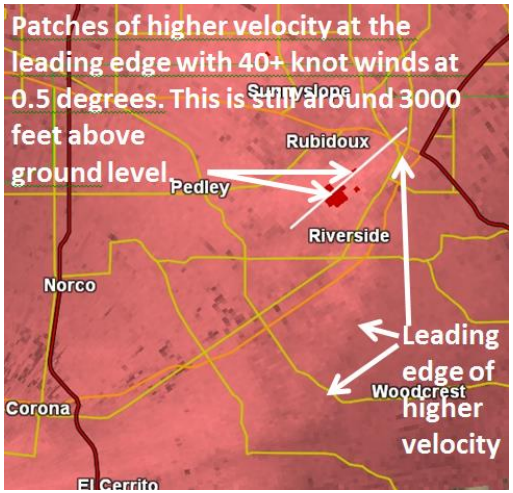
- Seven power poles and associated power lines were down in Riverside.

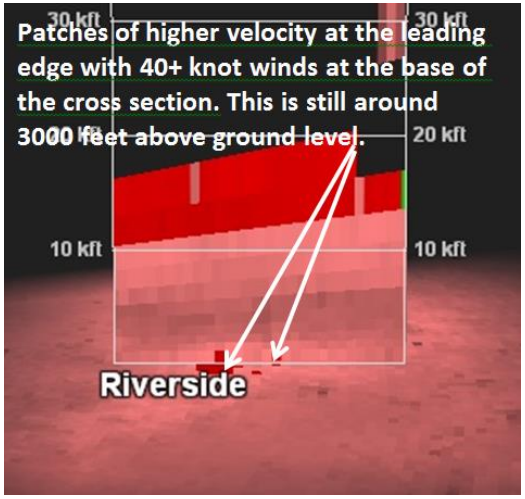
11-12 March 2016 - continued

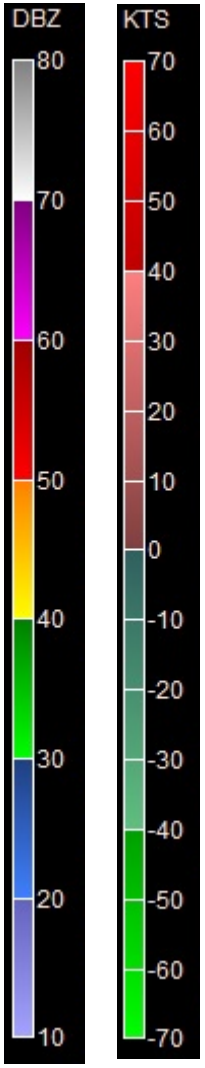








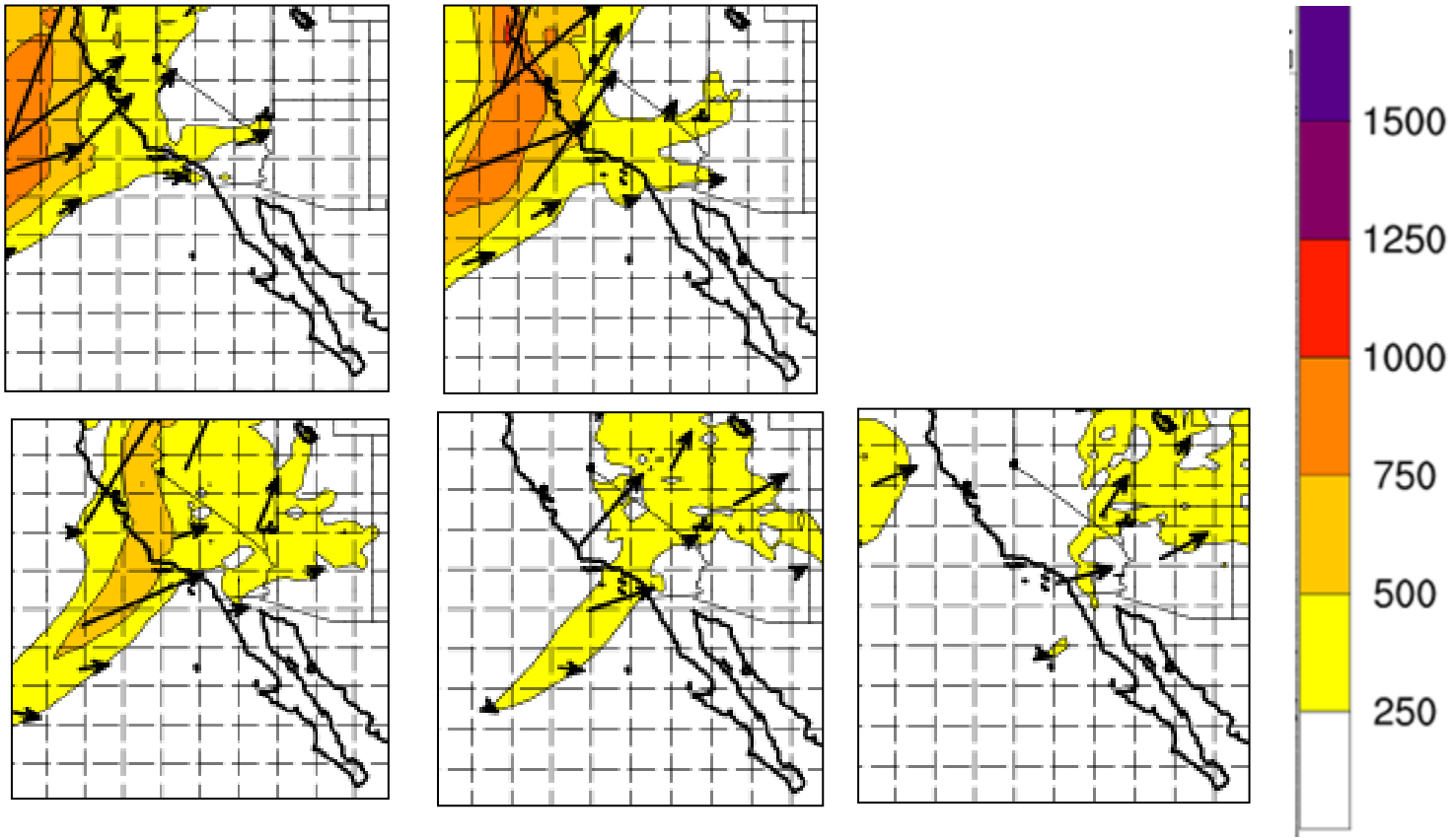




The upper row is the 500 hPA heights at 0000 UTC 12 March 2016 (upper left) and 0000 UTC 12 March 2016 KNKX sounding (upper right). The lower row of images is the KNKX Radar 0.5 degree base reflectivity (lower left), 0.5 degree velocity (lower, middle) and velocity cross section (lower right) at 2340 UTC 11 March 2016.

- Note again a fairly classical negatively-tilted trough
- Winds near the base of the cross section were around 40+ knots.

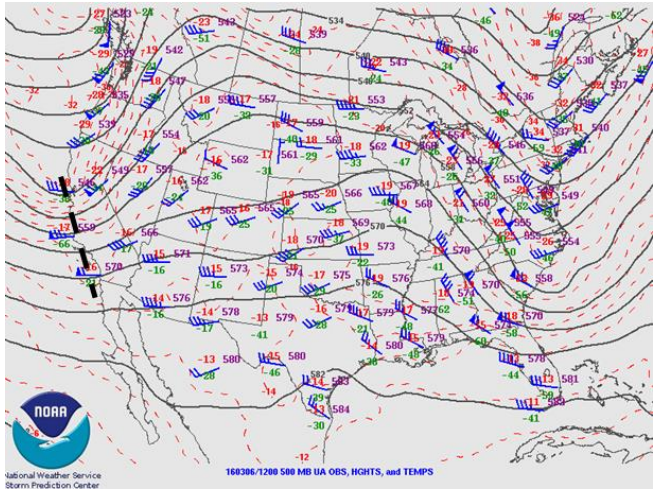
EVENT WITH NO REPORTED DAMAGE (5-6 March 2016)

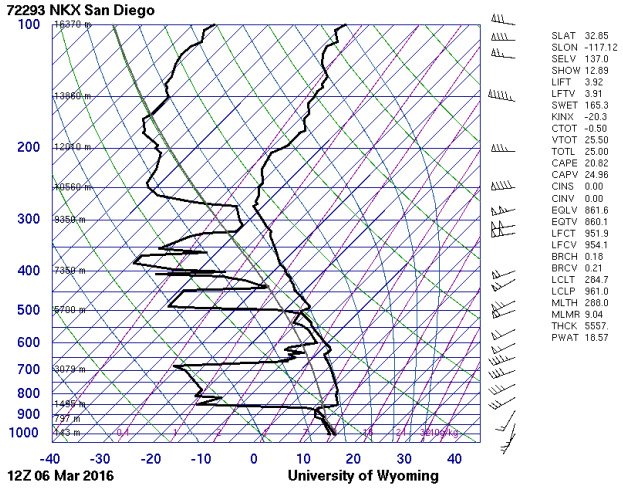


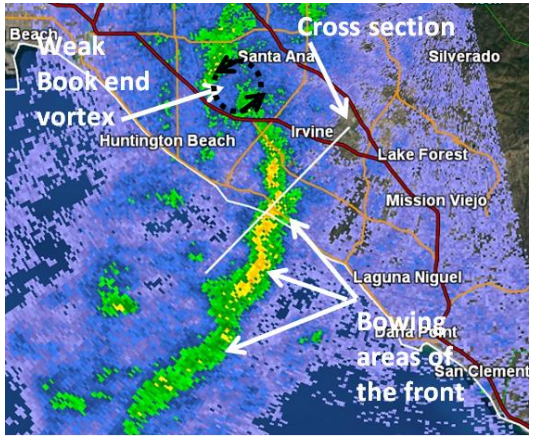
NCEP GFS IVT (kg m^{-1} s^{-1}) and IVT Vector initialized and valid at 1800 UTC 5 March 2016 (upper left) , 0000 UTC 6 March 2016 (upper right) , 0600 UTC 6 March 2016 (lower left) 1200 UTC 6 March 2016 (lower middle) and 1800 UTC 6 March 2016 (lower right) . Notice that the IVT250-499 moves toward Southern California, and extends inland but weakens as it moves in.

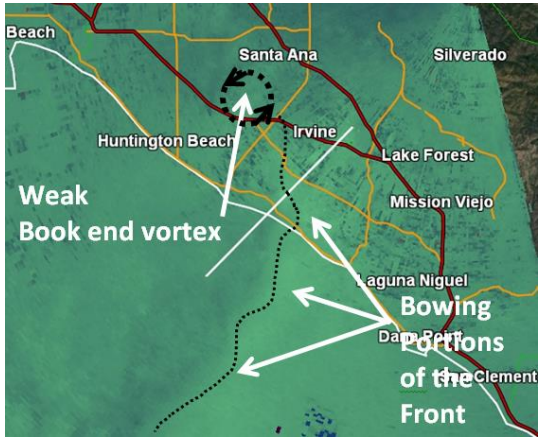
- Interestingly, this event had IVT magnitudes ≥250 kg m^{-1} s^{-1} extending inland, but no damage was reported.

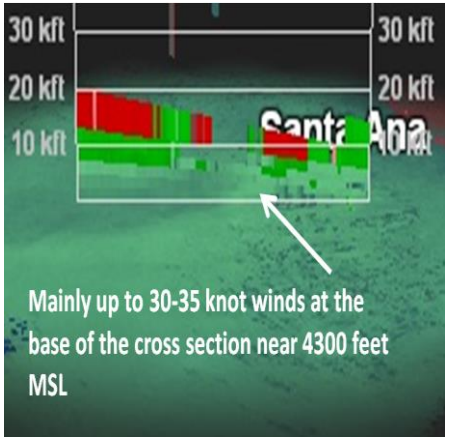
EVENT WITH NO REPORTED DAMAGE (5-6 March 2016) – continued

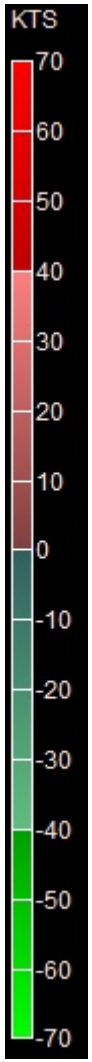








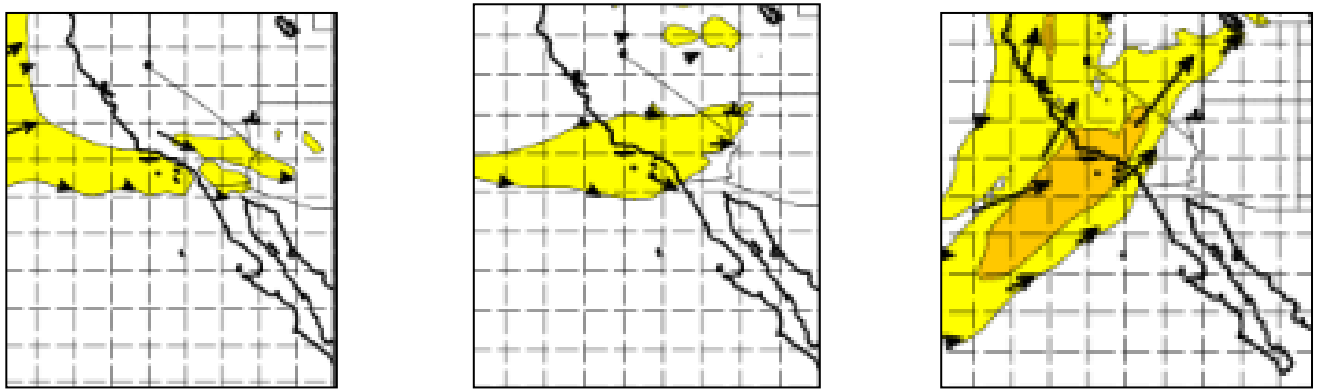


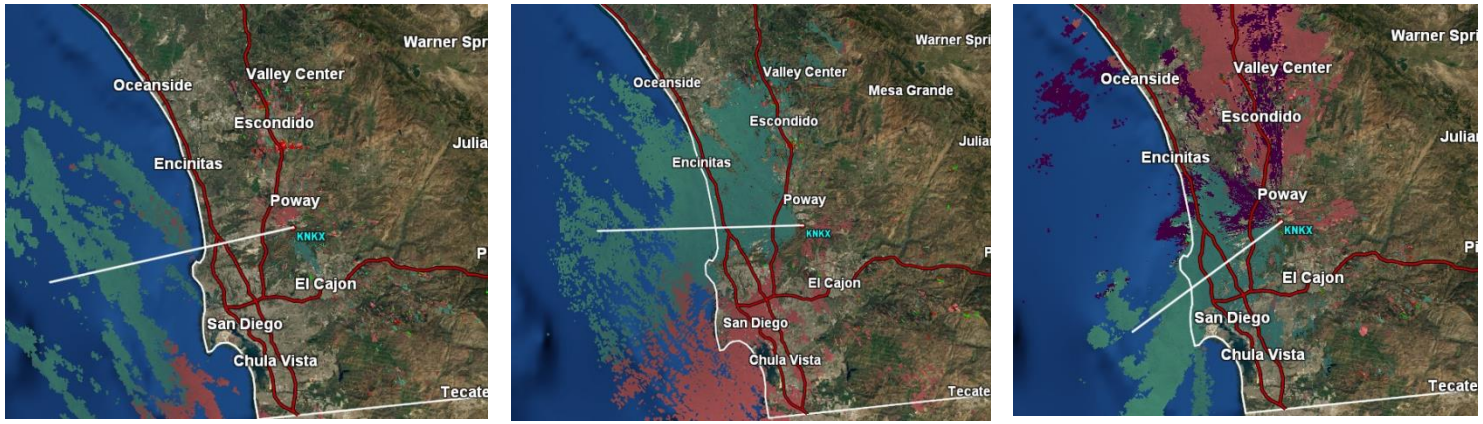


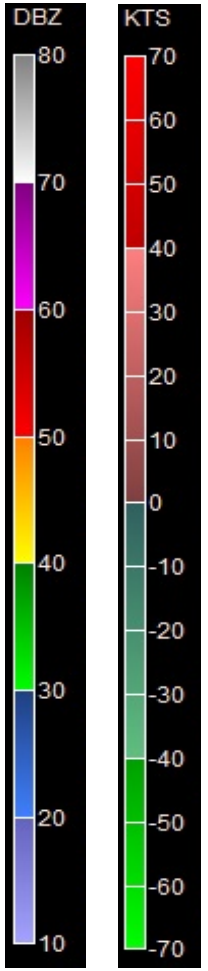
The upper images are the 500 hPa heights at 1200 UTC 6 March 2016 (upper left) and the 1200 UTC 6 March 2016 KNKX sounding (upper right). The lower images are the KNKX radar 0.5 degree base reflectivity (lower left), 0.5 degree base velocity (lower, middle) and velocity cross section (lower right) at 1414 UTC 6 March 2016.

- The 500 hPa chart and sounding show a negative tilt trough and 23 knot winds (11.5 m^{-1} s^{-1}) at 850 hPa.
- There were still some radar estimated 30-35 knot winds at the base of the 0.5 degree slice [it should be noted that the beam height is at about 4300 feet MSL, well above ground level since the radar antenna is on a mountain slope near 3100 feet MSL (near 0.95 km MSL) and the location of the bow is mainly in an area near sea level].
- There are good bowing structures and a bookend vortex, but still no surface damage per storm data.

ADDITIONAL DAYS WITH NO REPORTED DAMAGE







The upper row of images is the NCEP GFS IVT (kg m^{-1} s^{-1}) and IVT Vector initialized and valid at 1800 UTC 15 January 2016 (upper left), 0000 UTC 20 January 2016 (upper middle), and 1800 UTC 18 February 2016 (upper right). The lower row of images is their corresponding frontal passages near KSAN at 0030 UTC 16 January 2016 (lower left), 0430 UTC 20 January 2016 (lower middle) and at 0129 UTC 18 February 2016 (lower right) as seen in the 0.5 degree KNKX radar reflectivity data.

- These are the remaining days when IVT magnitudes ≥250 kg m^{-1} s^{-1} reached inland over Southern California. There was a similar peak wind in the radar data of only about 6-10 knots (3-5 m^{-1} s^{-1}) on all 3 events.
- Almost no rain anywhere with the 15 January 2016 case, a few hundredths in spots during the 20 January 2016 case, and widespread precipitation in the 18 February case (especially in the IVT magnitudes ≥500 kg m^{-1} s^{-1} area in the upper right IVT image shown above) that appears to have been strong enough to reach the San Diego Forecast Area

CONCLUSIONS AND TAKE-A-WAYS

- Be on the lookout for atmospheric rivers with IVT magnitudes ≥250 kg m^{-1} s^{-1} reaching inland past the coastline (with support from radar estimated winds and sounding 850 hPa winds), and especially with a negatively-tilted trough for potentially damaging events.
  - The events with damage generally had about 40 knot (20 m^{-1} s^{-1}) radar-indicated winds or higher in a layer at 2500 feet MSL (0.76 km MSL) and lower, and possibly down into the 30-40 knot (15-20 m^{-1} s^{-1}) wind category when storm structure was good (for example bow echo, well defined rear in-flow jets or book-end vortices).
    - Radar measurements of strong winds from about 2500 feet AGL and lower should be more frequent producers of damage than winds of the same magnitude but higher up.
    - There was one event that seemed to have most of the important characteristics, but no damage was reported.
      - Again, there is less certainty on the strong winds reaching the ground as the radar feature in that case was interrogated at around 3900 feet MSL due to the radar being located on a mountainside at around 3100 feet MSL and the beam was about 800 feet above radar level (ARL) at the location.
        - Remember, the base of the KSOX beam is already near 3100 feet MSL, (which is the height of the radar), so the beam is much higher than 2500 feet MSL
  - 850 hPa sounding winds were typically 25 knots (12.5 m^{-1} s^{-1}) or higher for the damaging cases. However, It was nearly 50 knots (25 m^{-1} s^{-1}) during the most extreme case, and resulted in 60+ knot (30+ m^{-1} s^{-1}) radar indicated winds below 2500 feet MSL.
  - These events were actually relatively shallow with relatively low echo tops, so these events can be quite shallow (possibly with little radar return at all) and still produce damaging winds.
  - One must be cognizant of which radar is being interrogated to get the best view of the event as well as know if the beam height is 2500 feet AGL (0.76 km) or lower for a more accurate estimate of the potentially surfacing winds.
  - Finally, more events will be gathered in the future to better examine these types of episodes in Southern California.

REFERENCES

- References:

  - Gibson Ridge Software, 2013: GRlevel2Analyst Version, 2.0. [Available online at http://www.grlevelx.com/.]
  - Ralph, F.M., P.J. Neiman, and G.A. Wick, 2004: Satellite and CALJET aircraft observations of 1997/98. *Mon. Wea. Rev.*, **132**, 1721-1745.
  - Zhu, Y., and R. E. Newell, 1998: A proposed algorithm for moisture fluxes from atmospheric rivers, *Mon. Wea. Rev.*, **126**, 725-735.

ADDITIONAL INFORMATION

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