# WES Case for Winter 2006: The 25 February 2004 San Francisco Urban Flash Flood Event

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## I. INTRODUCTION

Cool-season flooding is, on average, the most significant of the various short-fused weather-related hazards that occur in our CWA. As these also have some rather unique aspects in the sort of heavily urbanized environments that prevail within our CWA, we decided review of a relatively recent and significant urban flood occurrence would provide for a valuable WES training exercise. The case chosen was the 25 February 2004 San Francisco and San Mateo county flash flood event, which was driven by torrential short-term rainfalls associated with convective elements embedded in a land-falling Pacific cold front.

## II. METEOROLOGICAL OVERVIEW

A visible satellite image for 1645 UTC 25 February is shown in Figure 1, along with super-imposed 6-h AVN (GFS) forecast 500 mb height and 700 mb vertical velocity. This shows the frontal cloud band covering all of northern and central California with the cold front itself then extending NE to SW through San Francisco (Figure 2). The 500 mb height contours indicate strong mid-tropospheric flow and a vigorous embedded upper-level short-wave trough approaching the coast. The magnitude of the associated dynamical forcing is indicated by the GFS 700 mb vertical velocities, which reach a maximum value of ~ 26 $\mu$ bars $s^{-1}$.

A high-resolution (1-km) visible satellite image for the San Francisco Bay Region at 1700 UTC is shown in Figure 2, along with selected simultaneous surface and buoy observations. Time series analysis of observations (not shown), along with radar imagery (Figure 3) indicate that the frontal line was then oriented NNE to SSW through the city of San Francisco itself. Frontal passage had already occurred at the 2 buoys offshore from San Francisco, as well as at Napa County Airport (APC), but not yet at SFO. The strength of the low-level pressure gradient just ahead of the front is indicated by the magnitude of the wind speeds – with gusts to 54 kt (27 m $s^{-1}$) then reported by the southernmost of the depicted buoys, then still ahead of the front itself.

Detailed examination of the KMUX radar base reflectivities at the time of the frontal passage (and associated torrential rains and flooding) through SW San Francisco county and NW San Mateo county is provided in Figure 3. The time of the first panel (1627 UTC) is approximately 15 minutes after the very heavy flash flood producing precipitation began. A band of reflectivities in the 55-59 dBZ range then extended NE to SW along the front and directly over the area of interest. These values are of a similar magnitude to those seen in other cases with very strong Narrow Cold Frontal Rainbands (NCFRs) moving inland over central California.

What appears to be unusual in this case, however, is the length of time this band of maximum reflectivities persisted over the region of flash flooding. Comparison of Figure 3(b) with Figure

3(a) suggests the frontal band stalled over this area as a small wavelike feature propagated northward along the front just offshore from the San Mateo county coast. As it approached, the orientation of the portion of the frontal band over extreme SW San Francisco shifted more ENE to WSW, but remained largely stationary at this location until the wave moved through. This occurred at about the time of the last panel (1708 UTC), and coincident with the passage of the wave axis was an expansion of the area of high reflectivities to the rear of the frontal line, thus further prolonging the period of heavy precipitation.

Although no lightning strikes were reported in association with this frontal passage by either the National Lightning Detection Network (NLDN) or any of the standard surface observing network sites, radar and satellite imagery suggest that penetrative convection was occurring along the front. The 1200 UTC Eta-model forecast sounding for 1700 UTC at SFO is shown in Figure 4a. Aside from the depicted warm perturbation between 850 and 900 mb, the sounding is approximately moist-adiabatic. However, the surface temperature and dew point indicated in this sounding are 1-2 $^{o}$C lower than was actually observed at SFO just ahead of the front. When the sounding is modified by inclusion of these observed surface values, a small amount of lower tropospheric buoyancy (75 to 100 J $kg^{-1}$) results. But even a slight decrease in 850 to 500 mb temperatures from those projected by this model would result in potentially significant additional buoyancy on the order of several hundred J $kg^{-1}$. This can be sufficient to produce shallow supercellular convection if it occurs in conjunction with strong lower tropospheric (i.e., surface to 850 mb) speed and directional wind shear. The depicted model-forecast wind profile is consistent with this, as is the (prefrontal) hodograph from the actual 1200 UTC OAK sounding (OAK is about 15 km northeast of SFO), shown in Figure 4b. A waterspout was reported just west of the San Mateo county coastline.

## III. RAINFALL AND FLOODING

Maximum rainfalls occurred in the immediate vicinity of San Francisco State University (SFSU, see Figure 5 for location); an example of the sort of associated flooding that occurred in the vicinity of the SFSU Geosciences building is provided by the photo in Figure 6. A rain gauge in the City of San Francisco's Public Utility Commission (PUC) network sited on the roof of the Geosciences building at San Francisco State University recorded 1.90" of rain in the 45-min period ending at 1700 UTC (at which time electrical power and thus subsequent data were lost); 1.56" occurred within 30-min (and a maximum of 0.42" in 5-min). (This rain gauge, along with all associated system components, was subsequently checked for accuracy and found to be operating and measuring properly.) Streets on and near the SFSU campus, including major thoroughfares, flooded to depths estimated at 2 to 4 ft (0.6 to 1.2 m). Over 40 homes were seriously damaged, along with significant additional infrastructure losses (street washouts, damage to building contents, etc.). The final damage total was in excess of $20 million.

## IV. SUMMARY AND CONCLUSIONS

Between 1615 and 1715 UTC on the morning of 25 February 2004, record-level 5-min to1-hr rainfalls occurred over portions of southwestern San Francisco and extreme northwestern San Mateo County (Daly City). This took place as a mesoscale wave development occurred along the NCFR associated with a strong landfalling Pacific cold front, and caused a narrow zone of torrential precipitation to temporarily stall over the affected area. Although no lightning was detected or observed, lower-tropospheric buoyancy appears to have been greater than zero and there was evidence to suggest the presence of penetrative convection along the front. This locally torrential rainfall resulted in significant urban flooding in the affected areas. More than $20 million in damage is estimated to have occurred as a result.

The primary focus of the associated WES exercise was on the hydrologic aspects of this event – and, in particular, the diagnosis and short-term forecasting of flash flood level precipitation rates produced by winter season landfalling Pacific frontal systems. The use and limitations of WSR 88D derived 1-hr precipitation rates was considered in this regard. Examination of radar base reflectivity and velocity displays also revealed significant mesoscale organization along with the presence of some precursor severe convective weather signatures. However, no severe thunderstorms or tornadoes were observed in association with this NCFR (though there was one report of a waterspout offshore from the San Mateo county coast). This led to a second significant area of focus: the respective roles and interaction of shear and CAPE in the production of severe thunderstorms and tornadoes. In the WFO Monterey (greater San Francisco Bay Area) CWA, it is very uncommon for high levels of both shear and CAPE to occur in conjunction with each other – and this case was no exception. The CAPE associated with this NCFR as it moved through the San Francisco Bay Area was on the order of 100-200 J $kg^{-1}$, which in the presence of very strong lower-tropospheric speed and directional shear is sufficient to permit development of some signatures of significant mesoscale convective organization (e.g., bow-line segments along the NCFR). Although there was an absence of severe convective weather per se, the precursor mesoscale convective organization did appear to play a role in the development of the extraordinarily heavy precipitation rates that were locally observed. The strength of the front was also reflected in the strong surface straight-line winds that occurred in association with its approach and passage.

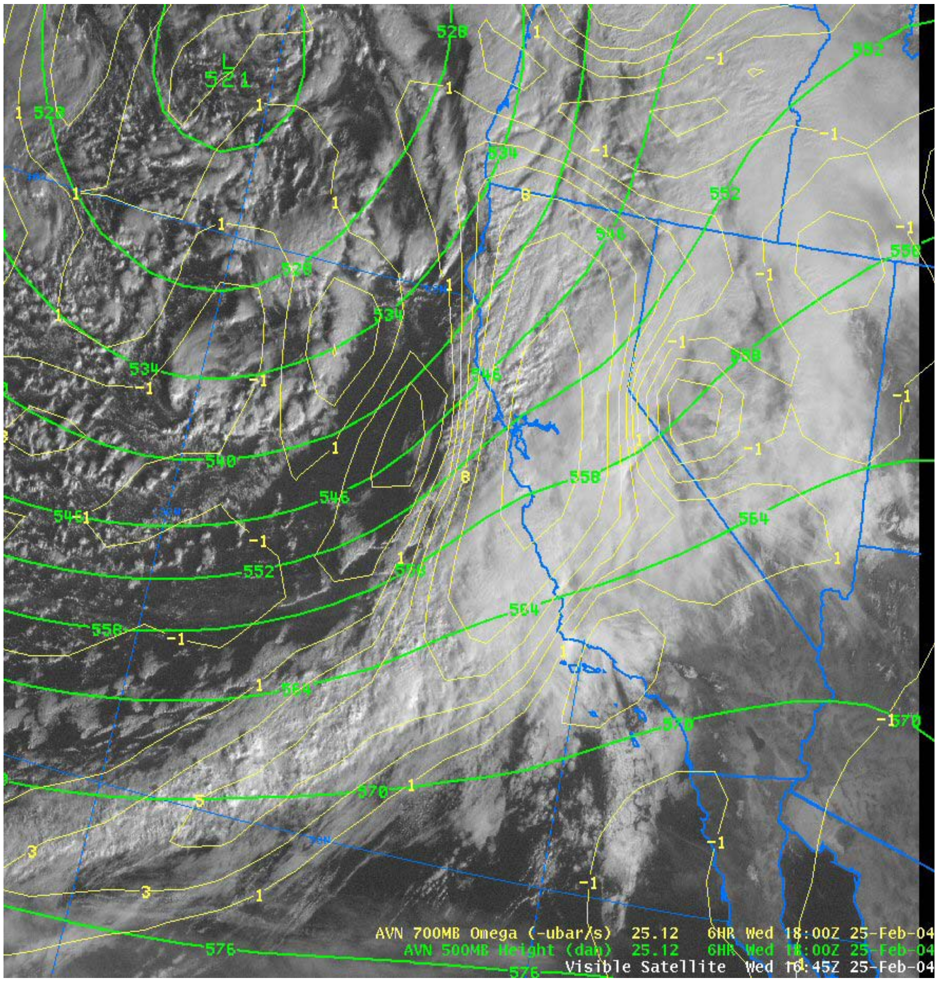


Figure 1. Visible satellite image for 1645 UTC 25 Feb with GFS 6-hr forecast 500 mb height contours (green lines, contour interval = 60 m) and 700 mb omega (yellow lines, varying interval; innermost isopleth = 24 $\mu$ bars $s^{-1}$) valid 1800 UTC.

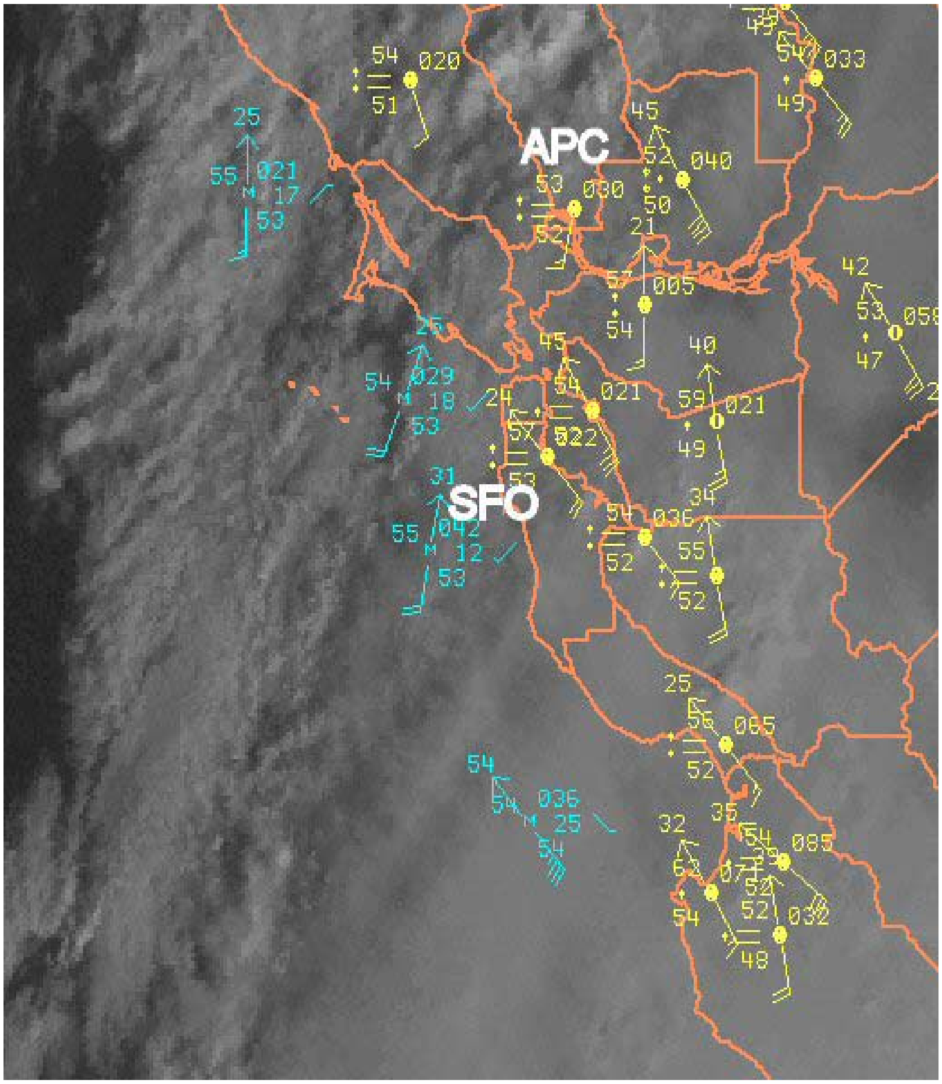


Figure 2. 1700 UTC Visible satellite image with 1700 UTC ASOS (yellow) and buoy (blue) observations superimposed. Locations of SFO (San Francisco International Airport) and APC (Napa County Airport) are indicated.

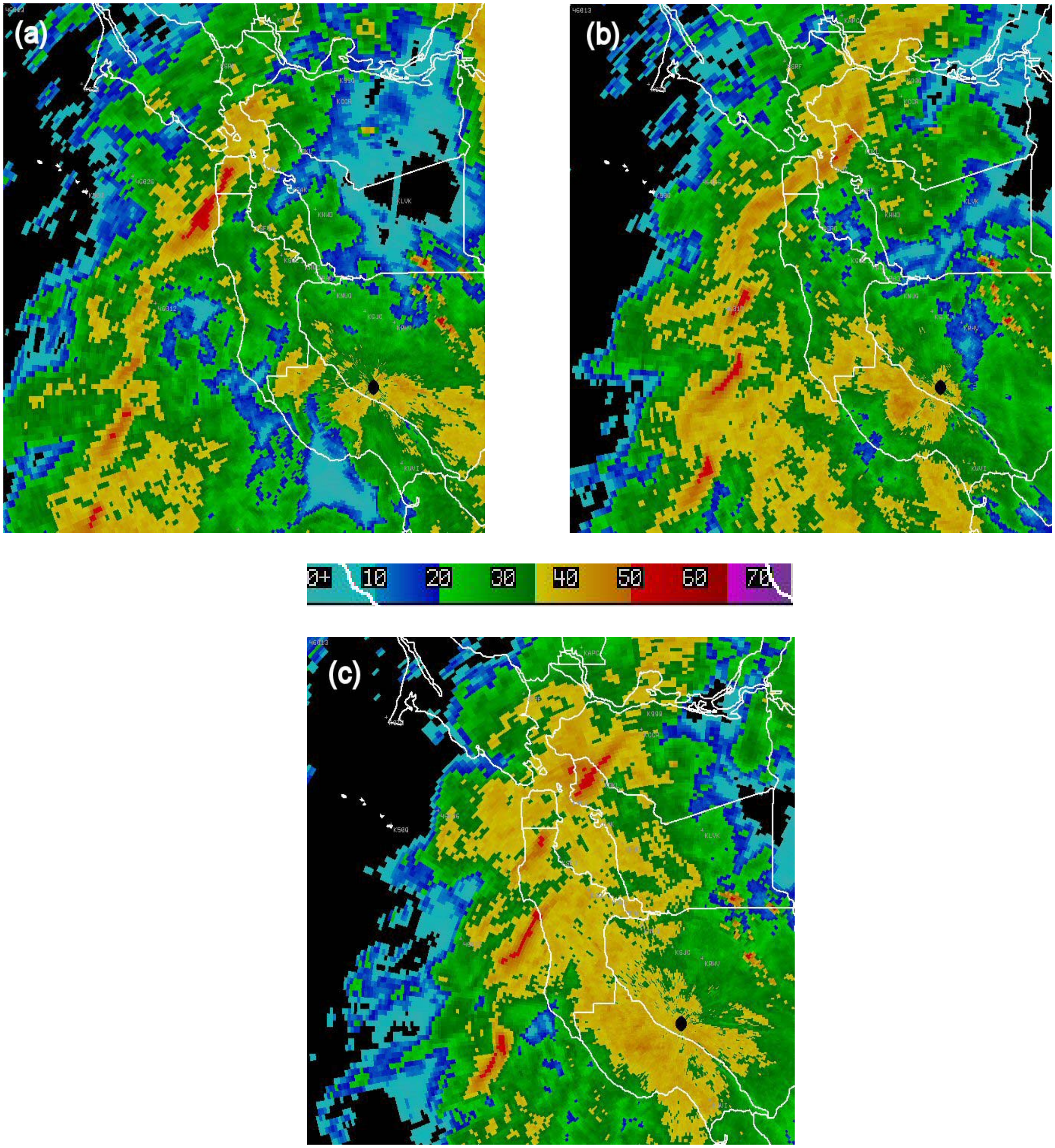


Figure 3. Series of base elevation (0.5$^{o}$ tilt) reflectivity images from KMUX WSR-88D radar (location indicated by the small black circle in the lower-right quadrant of each image, site elevation = 1030 m MSL) for (a) 1627 UTC, (b) 1645 UTC and (c) 1708 UTC 25 February. Reflectivity scale (dB Z) is indicated. Note that the beam elevation over SW San Francisco County is approximately 7000 ft (2133 m).

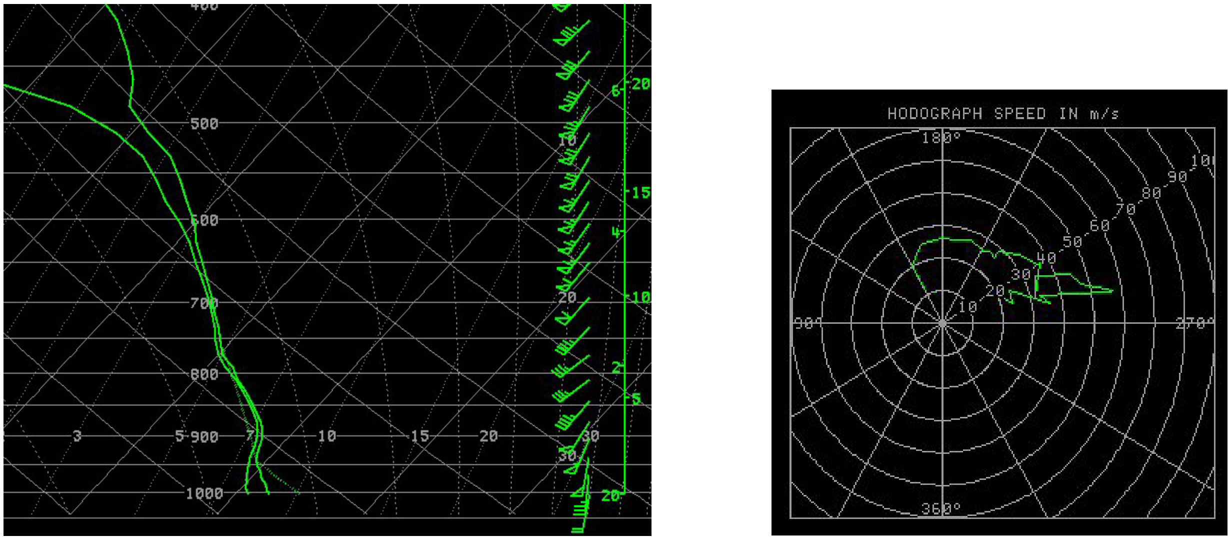


Figure 4.  (a) 1200 UTC initialized Eta model 5-hr forecast sounding for SFO valid at 1700 UTC. (b) Observed 1200 UTC OAK sounding hodograph.


Figure 5.  Topographic map of the central San Francisco Bay Region.  (SFSU = San Francisco State University)

Figure 6. Photo of the south access stairway of Thornton Hall (College of Science and Engineering; Geosciences) at SFSU, taken at approx 1715 UTC (9:15 am PST). (Photo courtesy of Drs. David Dempsey and Lisa White of the SFSU Department of Geosciences.)