THE HISTORIC SAN FRANCISCO FLASH FLOOD EVENT OF 25 FEBRUARY 2004

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1. INTRODUCTION

On 25 February 2004, torrential rain and extensive flash flooding occurred in portions of San Francisco and San Mateo counties, in association with a convective line embedded in a landfalling frontal band. Rainfall surveys indicate that between 1 and 1.5 in (2.5 to 3.8 cm) of rain occurred between 1630 and 1700 UTC (8:30 to 9:00 am LST) from NW San Mateo to SW San Francisco counties. Maximum rainfalls occurred in the immediate vicinity of San Francisco State University (SFSU, see Fig. 1 for location); a rain gauge on the roof of the Geosciences Building recorded 1.9 in (4.6 cm) in the 45-min period ending at 9:00 am. As a result, 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.

FIG. 1. Topographic map of the central San Francisco Bay Region.

2. METEOROLOGICAL OVERVIEW

The torrential rainfall responsible for the flash flooding occurred as a strong Pacific cold front moved onshore. Visible satellite imagery for 1645 UTC 25 February (Fig. 2) 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 (Fig. 3). Superimposed 500 mb

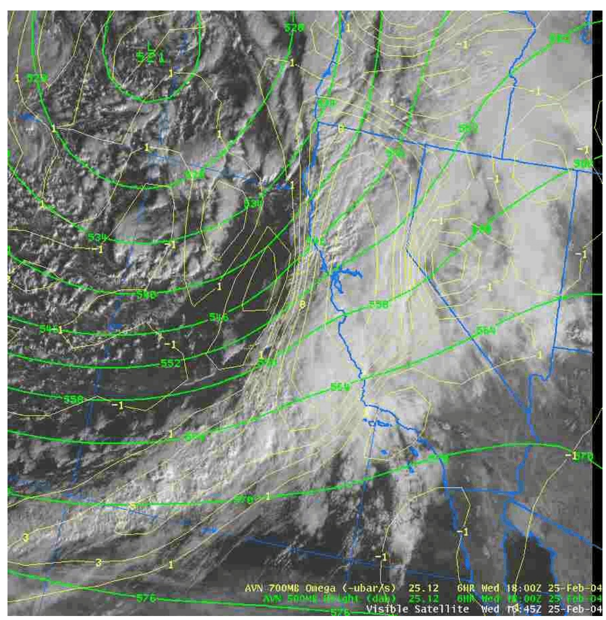


FIG. 2. Visible satellite image for 1645 UTC 25 Feb with GFS 6-hr forecast 500 mb height contours (green lines, contour interval = 60 m) and 700 mb omega (yellow lines, varying interval) valid 1800 UTC.

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 bars s^{-1}.

A high-resolution (1-km) visible satellite image for the San Francisco Bay Region at 1700 UTC is shown in Fig. 3, along with selected simultaneous surface and buoy observations. Time series analysis of observations (not shown), along with radar imagery (e.g., Fig. 4) 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

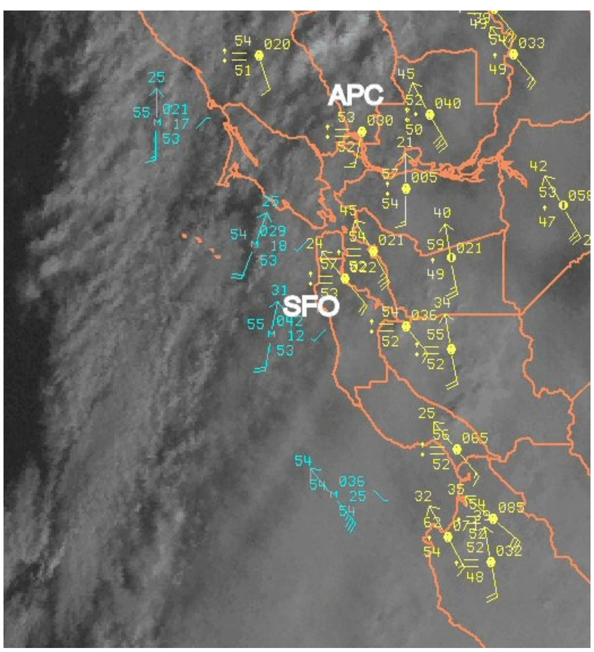


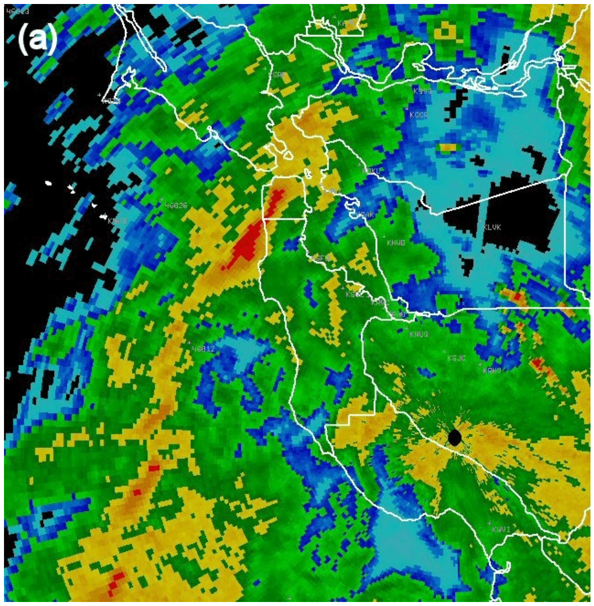
FIG. 3. 1700 UTC Visible satellite image with 1700 UTC ASOS (yellow) and buoy (blue) observations superimposed. Locations of SFO (San Francisco International Airport) and APC (Napa County Airport) are indicated.

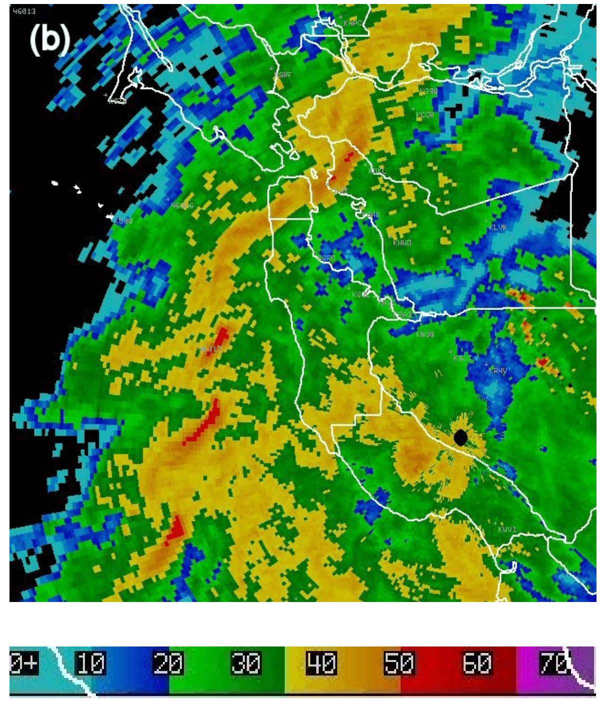
to 54 kt (27 m s^{-1}) then reported by the southernmost of the depicted buoys, then still ahead of the front itself.

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 Fig. 4. The time of the first panel (1627 UTC) approximately corresponds to the when 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 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 appeared to persist over the region of flash flooding. Comparison of Fig 4(b) with Fig 4(a) suggests the frontal band stalled over this area as a small wave-like 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 occured at about the time of the last panel (1708 UTC), but 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





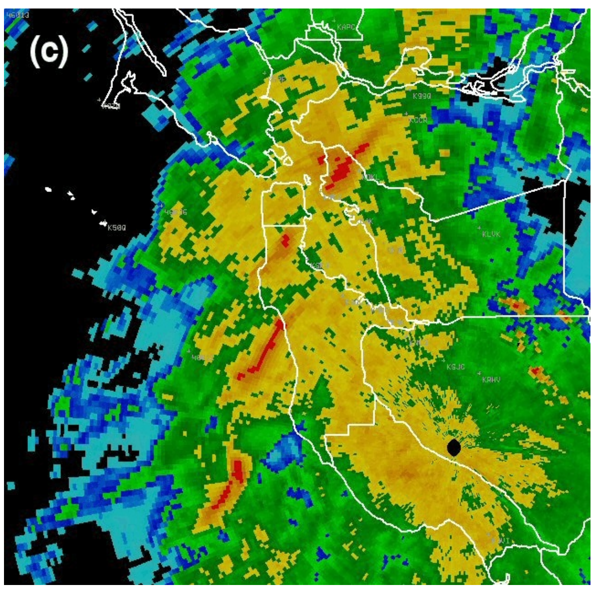


FIG. 4. Series of base elevation (0.5° tilt) reflectivity images from KMUX WSR-88D radar (location indicated by the small black circle in the lower-right quadrant of each image, site elevation = 1030 m MSL) for (a) 1627 UTC, (b) 1645 UTC and (c) 1708 UTC 25 February. Reflectivity scale (dBZ) is indicated. Note that the beam elevation over SW San Francisco County is approximately 7000 ft (2133 m).

was occurring along the front. The 1200 UTC Eta-model forecast sounding for 1700 UTC at SFO is shown in Fig. 5a. 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 each 1-2 C lower than was actually observed at SFO just ahead of the front. Adjusting for this results in a small amount of lower-tropospheric buoyancy (75 to 100 J kg^{-1}). 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 Fig 5b. A waterspout was reported just west of the San Mateo county coastline.

3. RAINFALL AND FLOODING

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). Examples of the associated flooding in the vicinity of the SFSU Geosciences building are provided by the photos in Figs. 6 and 7. As was noted in the Introduction, total damage to homes, other buildings and infrastructure, has been estimated to be in excess of $20 million.

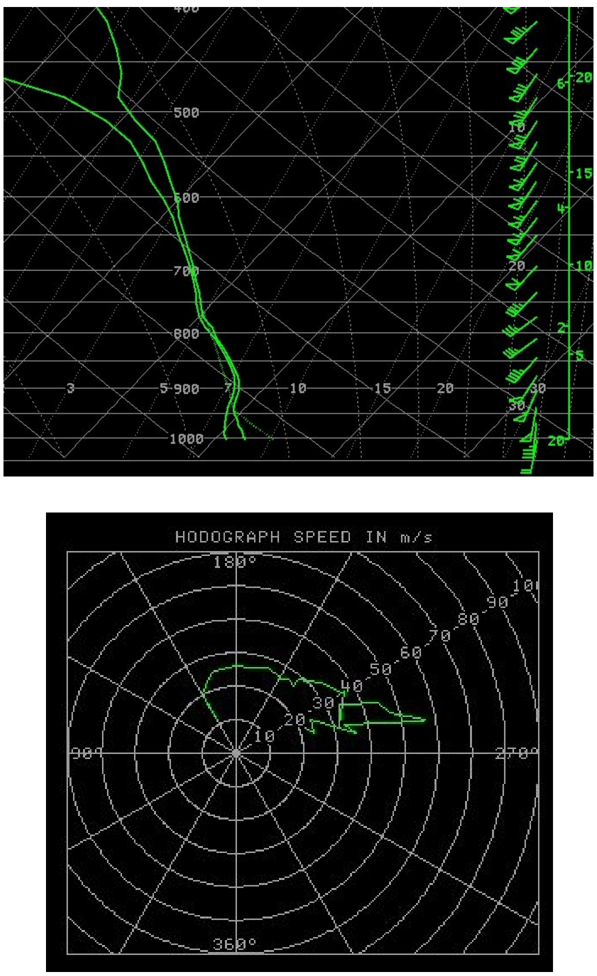


FIG. 5. (a) 1200 UTC initialized Eta model 5-hr forecast sounding for SFO valid at 1700 UTC.
(b) Observed 1200 UTC OAK sounding hodograph.

FIG. 6. Photo of the 2nd author standing next to the access road on the north side of the SFSU Geosciences building taken at approx 1715 UTC (9:15 am PST). The water extends to curb level and is about 2 ft (0.6 m) deep at the middle of the road.

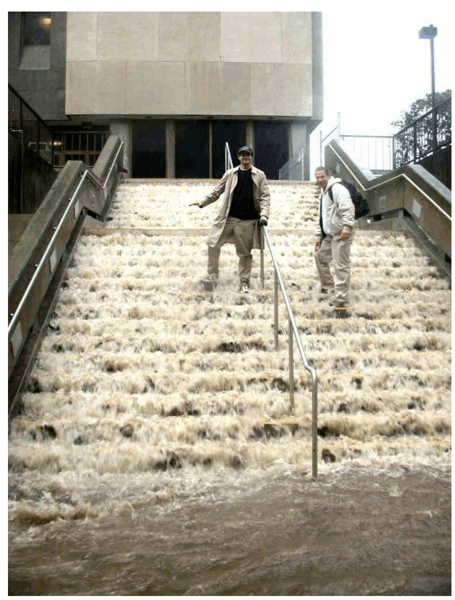


FIG. 7. Photo of the south access stairway of Thornton Hall (College of Science and Engineering; Geosciences) at SFSU, taken at approx 1715 UTC (9:15 am PST).

Using data from the 15 available gauges (out of 21 total) in the San Francisco PUC rain gauge network, in conjunction with the California Department of Water Resources calculated rainfall-depth-duration frequencies for peak 30-min amounts, the return periods for the maximum 30-min totals were determined and plotted (Fig. 8). Given the limited number of stations, details in the positioning of the isopleths should not be interpreted too closely, especially in the strong gradient region to the east of SFSU, where reports from several gauges were missing. Nonetheless, the finding that this was at least a 1000-yr rainfall event for a portion of southwestern San Francisco appears robust. Additionally, rainfall data from the one gauge at SFSU yields a 10,000-yr return period. As return periods of this magnitude vastly exceed the actual period of record, their quantitative robustness is limited. Nonetheless, they do provide statistical evidence for both the extreme magnitude and rarity of this event.

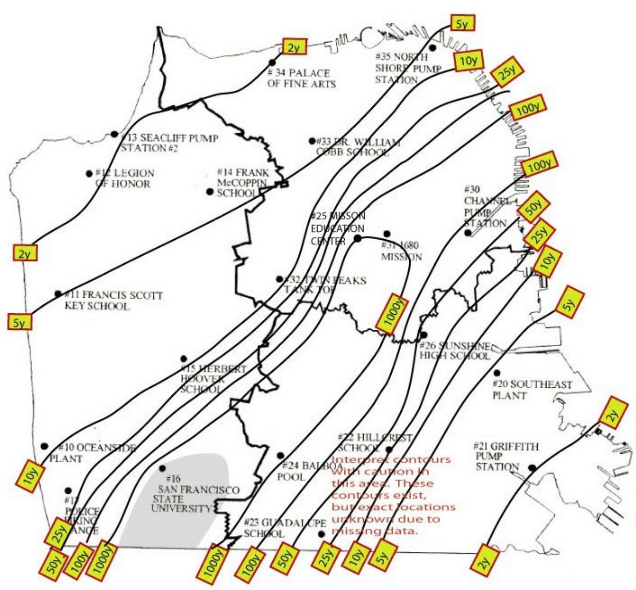


FIG. 8. San Francisco public utilities commission rain gauge network. Return periods (years) are indicated for peak 30-min rainfall amounts observed during the morning of 25 February 2004. Analysis is based on data from 15 gauges; 6 gauges did not report (#11, #22, #23, #24, #30 and #32).

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