P15.2

The 12 November 2003 Los Angeles Hailstorm

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1. Introduction

On 12 November 2003, a powerful yet spatially compact hail producing storm formed and then remained quasi-stationary over South Central LA, just east of Los Angeles International Airport (LAX). Precipitation exceeding 5 inches, along with pea-size hail drifting to several feet, were recorded in an area encompassing just a few square kilometers while nearby gages showed modest, if any, accumulations (Table 1). The daily operational MM5 run at UCLA captured the storm's development and rough location despite rather coarse (6 km) resolution and economical microphysics being employed. The forcing mechanisms for storm genesis and (lack of) movement are examined using still higher resolution simulations, mainly employing more sophisticated physics. These simulations are not always better than the operational run; indeed, some are much worse. This case has also been simulated with the WRF model.

Table 1: Precipitation (mm) and distance (km) from 96th St. gage

Gage	Precip.	Distance
96th/Central	136.1	–
Ducommon St.	18.0	11.2
LA River	6.9	7.6
LA City Coll.	3.1	15.2
Dominguez	3.1	13.2
Ballona Ck.	1.5	14.8
La Mirada	1.5	24.1

2. Background

On the afternoon of the 12th, a cut-off low that had been present over the Southern California Bight migrated eastward over the Los Angeles basin, bringing moist, unstable air from the south and southwest. Meanwhile, light rain had been recorded earlier in the day in the mountains east of LA, and also out in the Mojave Desert to the northeast. Colder temperatures in this high elevation desert contributed to offshore flow, a common occurrence during winter. Light rain began falling at the tipping bucket gage at 96th and Central, in South Central, around 2227Z (2:27 PM local); see Fig. 1. Heavy rain started there around 2330Z and persisted for just over 2.5 hours. The largest rain rate noted during this period was 174 mm h^{-1}, at 0103Z on the 13th. By the time rain finally ceased at 0403Z (8:03 PM), the gauge had recorded 136 mm (Table 1). Copious hail also fell in this general area, with an unknown effect on the precipitation collector. Noticeable amounts of hail were still present in the area two days later.

In the hours prior to the development of the hailstorm, radar revealed scattered echoes moving generally from the south over West LA and and the adjacent ocean. A sequence of relatively bright but short-lived echoes formed in this area, several kilometers west of where the hailstorm subsequently appeared, but these produced only light rain. The hailstorm could have formed on the southeast flank of these cells as the latter dissipated and moved north towards the mountains. Figure 2 shows the 0105Z radar image from the Santa Ana radar, around the time of the maximum recorded rainfall. An observer located to the east of the hailstorm (P. Magallanes, pers. comm.) reported seeing a line of "feeder cumuli" arrayed to the south, consisting of cells merging in with the main storm. He reported that this configuration persisted with little change for over two hours.

3. Operational MM5 run

The MM5 model is run real-time at UCLA for research and educational purposes. The model has 23 vertical levels and is triply nested with 6 km resolution in a domain straddling the LA area. Simple ice microphysics is employed along with the Kain-

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Fritsch 2 cumulus parameterization in the two coarser meshes. The MRF planetary boundary layer (PBL) package is used. Initial and boundary conditions are provided by the 40 km Eta gridded product, and integration commenced from a cold start at 12Z (4 AM).

Precipitation accumulations in the operational run's 6 km domain are shown in Fig. 3. A prominent bullseye in rain rate is seen in the LA basin, south and west of the mountains that surround the area. Compared to the observations, the maximum precipitation is underpredicted (by 41%) and located too far to the east. In the model, rain started after 0100Z (5 PM), later than observed, in the foothills south of Pasadena. Precipitation increased through 0500Z as the convection migrated slowly to the southwest, closer to where the actual storm became anchored. As rainfall waned thereafter, the precipitation center retreated eastward. Despite position and timing discrepancies, this forecast is judged to be fair to good, particularly considering how rare storms of this magnitude and compactness are over the lower elevation portions of the LA basin.

4. Higher resolution MM5 runs

Encouraged by the success of the operational run, higher resolution simulations of this case were attempted. Four telescoping, two-way nests were used, with the finest (1 km) mesh placed over the lower elevation section of the LA basin. Domains 3 and 4 are shown in Fig. 4. The best simulation generated thusfar employed Reisner 2 microphysics without any cumulus parameterization, even in the 27 km outermost domain. The precipitation accumulation from this simulation is shown in Fig. 5. Rainfall is still underestimated, and the model did not predict any precipitating ice at the ground[1]. However, there is a precipitation maximum much closer to the location where the actual hailstorm became stationary. The radar estimated storm total rainfall through 0415Z is shown for a roughly similar area in Fig. 6. The observed and predicted patterns bear some resemblance.

This higher resolution model simulation appears to have created a precipitating storm in the LA basin for a different reason than the operational run. In this simulation, precipitating convection cropped up near the Puente Hills (see the northeast quadrant of Fig. 7) before 2230Z (2:30 PM), possibly the result of the outflow from an earlier and weak storm located farther to the east. The more substantial outflow from this storm subsequently spread westward, reaching the South Central area by 0130Z. Convection was initiated along this boundary shortly thereafter. However, though the outflow continued to propagate, the convection remained essentially stationary over the region of initiation. Figure 7 displays the situation at 0230Z; the readily visible cold outflow has reached the coastline west of the principal model convection by this time.

Figure 8 tracks the CAPE field as it approached the Puente Hills. The relatively high CAPE (up to $\approx$ 1000 J) arrived there by 2230Z, the second time shown, initiating the convection mentioned above. By the third time (0030Z or 4:30 PM) that convection's cold outflow was starting to oppose the further inland penetration of the high CAPE air, and indeed started pushing it back towards South Central. As in the operational run, the South Central convection was unrealistically late, only appearing during dusk; at this time, the actual storm was already declining in strength. This probably had a deleterious impact at least on simulated storm strength since the inflowing air's CAPE declined rapidly as the lower troposphere cooled after sunset.

Why did the model develop convection in the west LA area so late? If the actual storm was also triggered by previous convection in the eastern portion of the basin, it is likely that activity was also delayed in the model. As mentioned earlier, there was precipitation to the east and northeast earlier in the day, and a station at Whittier – located just west of the Puente Hills, 24 km east of the 96th St. gage – recorded the passage of a front-like feature around 2100Z (1 PM; see Fig. 9). In the model, the mesoscale cold front seen on Fig. 7 did not pass Whittier until about 0000Z, three hours too late.

Further, the high CAPE air did not progress towards the LA area until after 1830Z (10:30 AM), when the previously strong offshore flow began to abate. The model's offshore flow may have been too strong or started weakening too late, or perhaps the cut-off low's movement into the area was too slow. It is possible that the early afternoon convection in West LA accelerated or augmented the hailstorm; that was completely missing in the MM5 simulations.

When this high resolution simulation was rerun without domain #4, no precipitation occurred over the

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[1] An ARPS cloud model storm made with a sounding extracted from this MM5 run was a very prodigious hail producer. That simulation employed microphysical alterations discussed in Wakimoto et al. (2004)

South Central area at all. Without the 1 km nest, the Puente Hills cannot be resolved, and the early afternoon convection made its appearance still farther to the east. When the high CAPE air entered into the basin, it flowed without impediment up against the San Gabriel mountains to the north instead of becoming lifted over South Central. An otherwise identical simulation that employed the less sophisticated simple ice microphysics used in the operational run also managed to generate precipitation almost everywhere except in South Central (Fig. 10). Again, the bulk of the rainfall occurred on the slopes of the San Gabriel mountains.

5. WRF simulations

A simulation made using version 2 of the WRF model will now be described. This run utilized a single domain at 3 km resolution along with stock Lin et al. microphysics and the YSU boundary layer parameterization. This simulation was also initialized with the 40 km Eta model product with a cold start at 12Z.

Figure 11 shows the CAPE and 10 m wind fields at six times spanning the event. As in the MM5 run, relatively strong offshore flow was noted early in the day, with a region of convectively favorable air lurking offshore. The WRF simulation, however, quickly generated a fair amount of rainfall in the Mojave Desert (northeast of the LA basin) and intervening mountain ranges [panels (b) and (c)]. This helped maintain and intensify the offshore winds, at a time of day in which those winds are usually decreasing in strength. The collision of the offshore winds with the high CAPE air apparently initiated some short-lived convection just offshore of Malibu and West LA around 2100Z (1 PM). Radar imagery from this time (Fig. 12) shows echoes both in the Mojave and along the coast in Malibu.

The model also produced some convection over West LA, just inland from the coastline. As alluded to earlier, radar echoes did appear there about 40 min after the time of Fig. 12. Precipitation in the LA basin began in earnest around 2300Z (3 PM), roughly coincident with the onset of heavier rainfall at the 96th St. gage. Figure 11 shows the precipitation remained localized over the western LA basin [panel (e)] and declined with the CAPE into the evening hours [panel (f)].

As in the MM5 simulation, prior convection occurring to the east of the hailstorm location appears to have played a major role in determining the location and timing of the afternoon storm. In this WRF run, however, the crucial precipitation was that falling in the Mojave and mountains to the northeast rather than the nearby (and essentially unresolved) Puente Hills. As shown in Fig. 11, the winds remain easterly over West LA until midafternoon. That had the effect of keeping the high CAPE air from progressing inland. Convection is initiated, however, as the northerly flow to the south of the hailstorm location finally succeeded in bringing the high CAPE inland to the South Central area. That occurred in the interval between Figs. 11c and d.

The importance of the prior convection in keeping the high CAPE air at bay in this WRF run is demonstrated in Fig. 13. This figure presents the results of two additional WRF simulations employing the simpler Kessler "warm rain" microphysics for convenience. For the right-side panels, however, cloud-to-rain autoconversion was deactivated, precluding the development of precipitation. While the standard Kessler run looks quite comparable to its Lin microphysics counterpart (Fig. 11), the removal of the precipitation process had a dramatic impact on the results. Without evaporation cooling in the mountains and Mojave Desert, the offshore flow weakened during the morning hours, removing the obstacle that kept the high CAPE air over the ocean. Instead, by 2100Z, the convectively favorable air had reached the mountains ringing the northern portion of the LA basin. Had autoconversion been activated at this time, precipitation would undoubtedly have fallen in the higher elevations rather than over the flatter region to the south.

A more detailed intercomparison of the MM5 and WRF simulations with the observations and each other is in progress.

6. References

Wakimoto, R. M., H. V. Murphey, R. G. Fovell, and W.-C. Lee, 2004: Mantle echoes associated with deep convection: Observations and numerical simulations. *Mon. Wea. Rev.*, **132**, 1701-1720.

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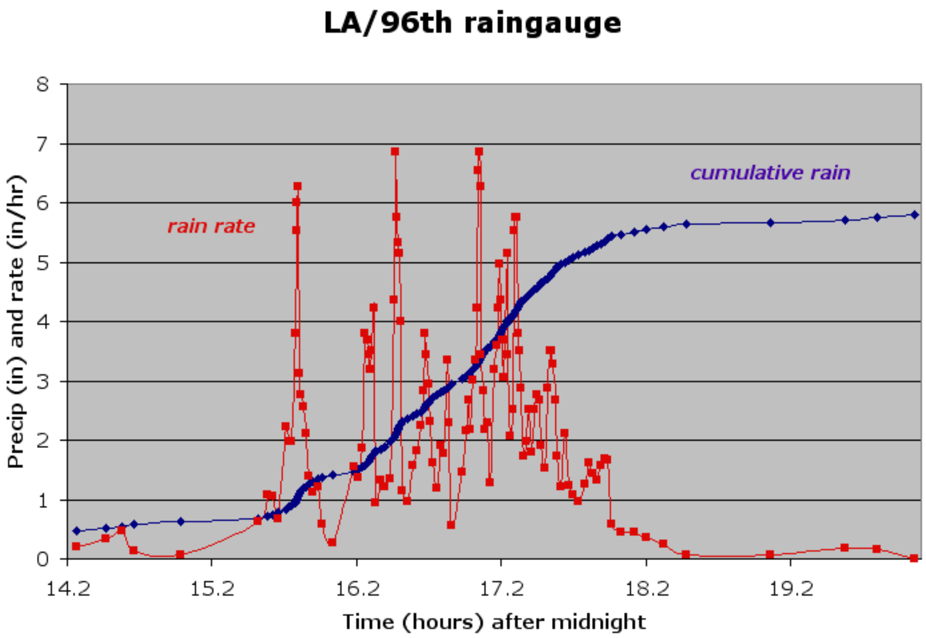

Fig. 1: Time series from the rain gage at 96th and Central, the closest gage to the storm's center.

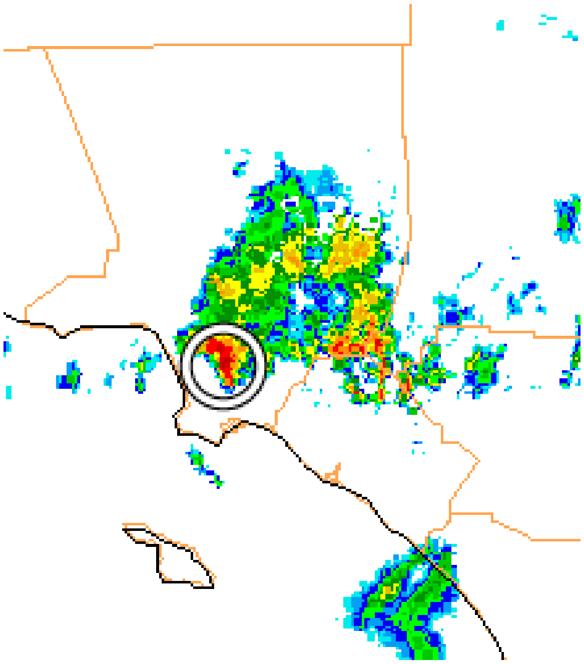

Fig. 2: KSOX radar image for 0105Z 13 Nov 2003. The circled echo was by far the brightest on the image.

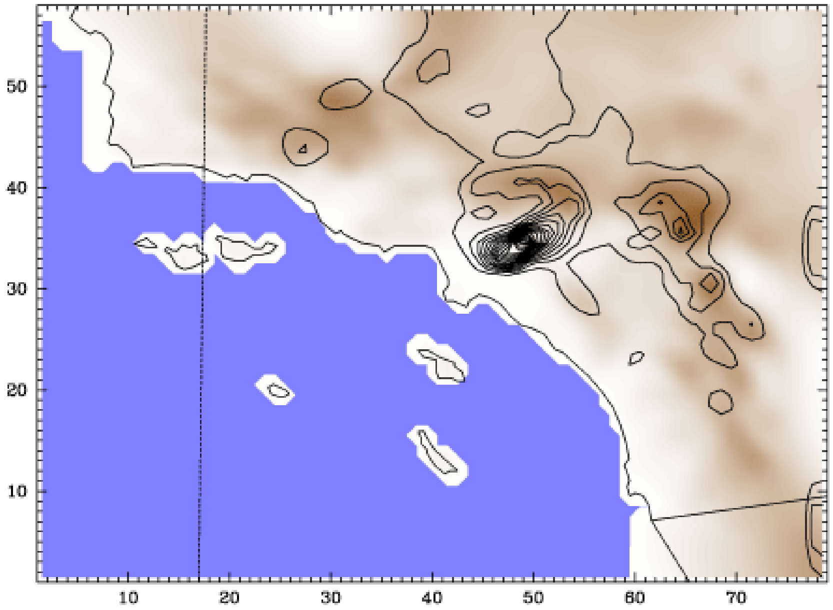

Fig. 3: Precipitation accumulation in 6 km domain in the operational MM5 run. Maximum value: 80 mm. Topography field shaded.

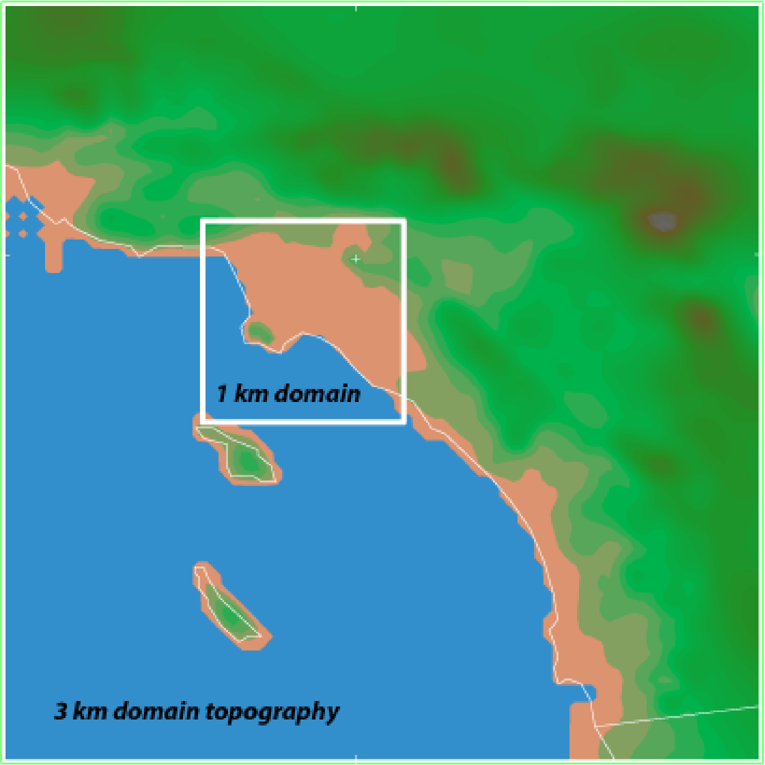

Fig. 4: Topography of domain 3 from the higher resolution MM5 runs. Location of the 1 km nest is indicated.

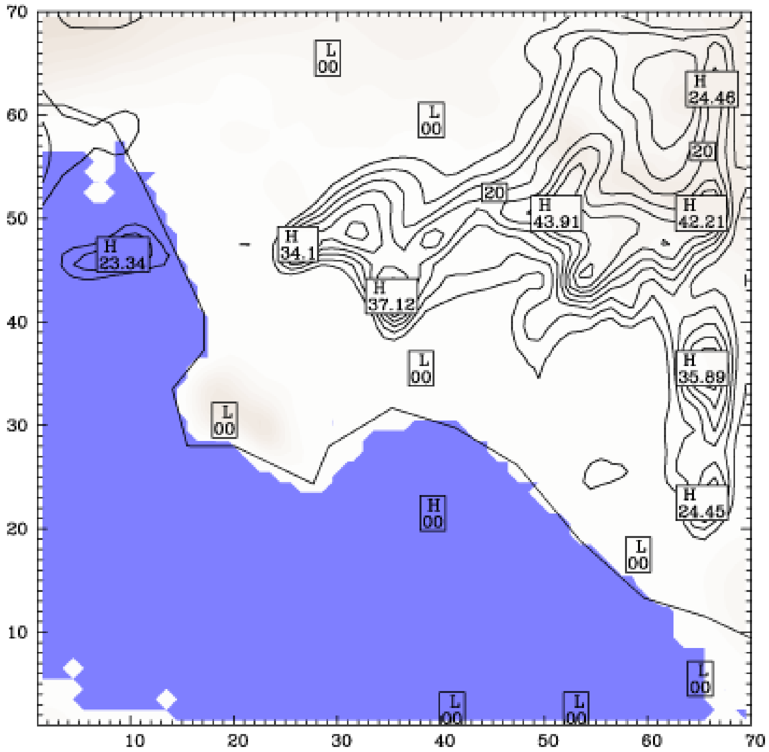

Fig. 5: Precipitation accumulation (mm) in the higher resolution MM5 run's 1 km domain of a four-nest run employing Reisner 2 microphysics.

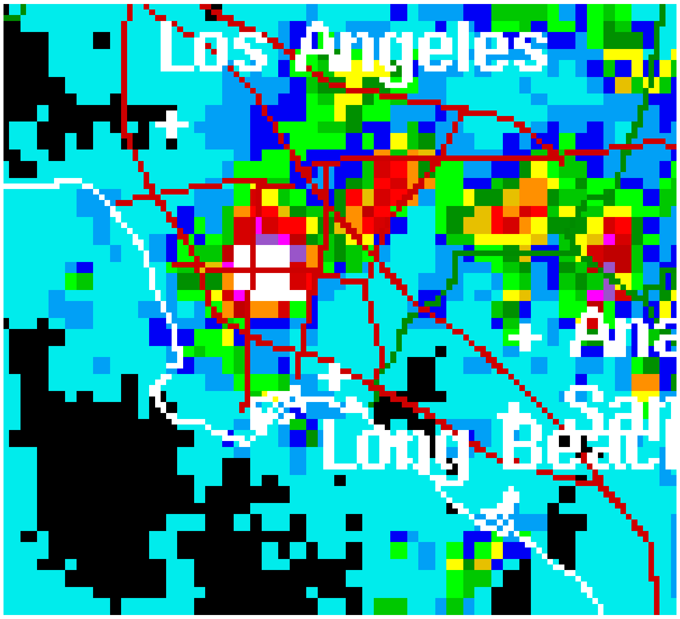

Fig. 6: Radar estimated storm total rainfall from the KSOX radar by 0415Z. Precipitation exceeded 5 inches in white area.

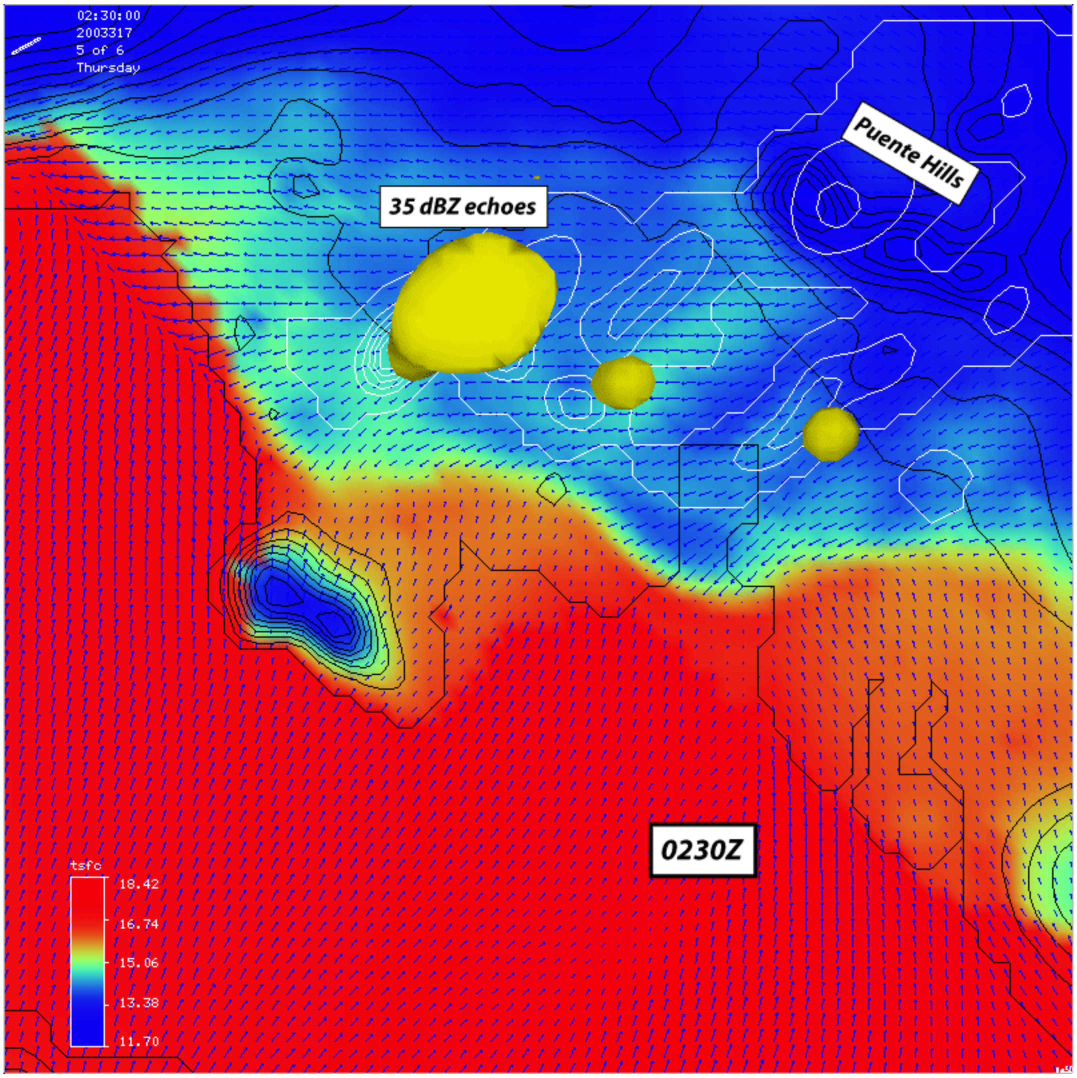

Fig. 7: View of the high resolution MM5 run's 1 km domain at 0230Z. Colored field is surface temperature. White contours: last 15 min precipitation accumulation; black contours: terrain. Vectors show 10 m winds.

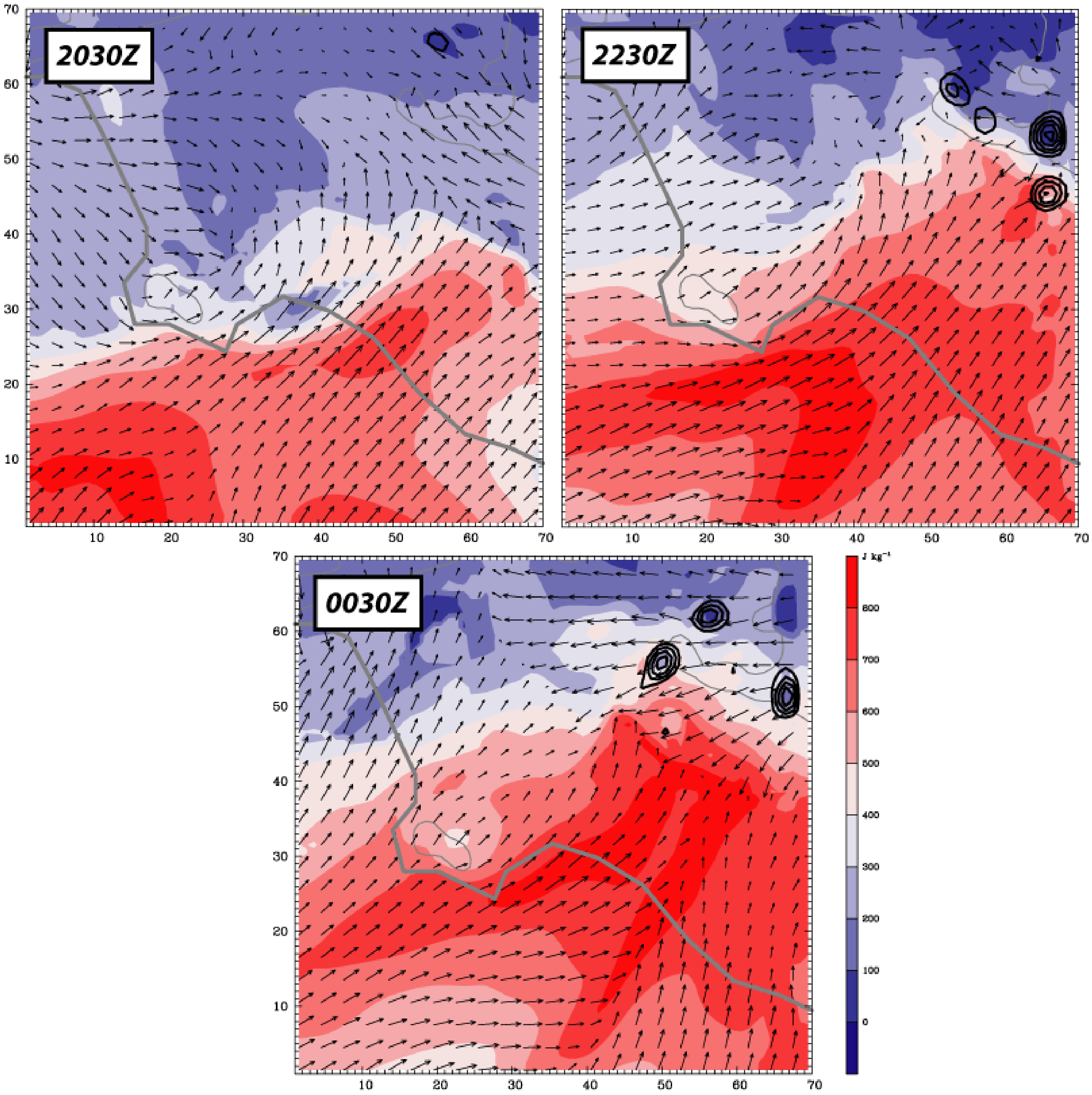

Fig. 8: CAPE (colored field) distributions and 10 m winds (every third gridpoint) for 2030, 2230 and 0030Z from the higher resolution MM5 run's 1 km domain. Black contours show vertically integrated non-precipitating water (2 mm interval). Topography depicted with grey 200 m contours.

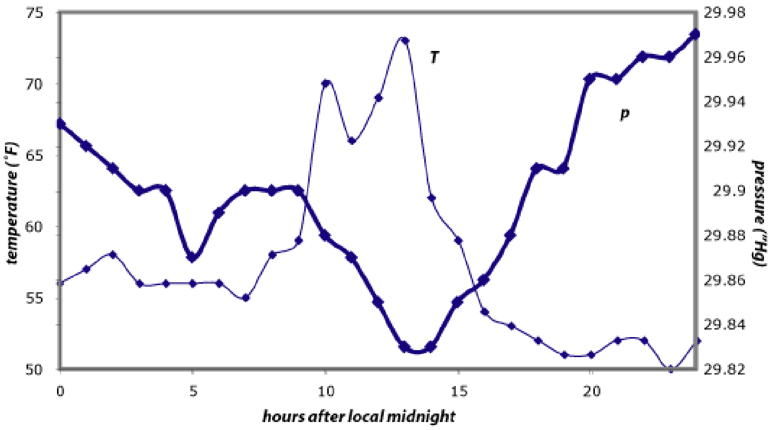

Fig. 9: Time series of temperature and pressure at Whittier, located east of South Central.

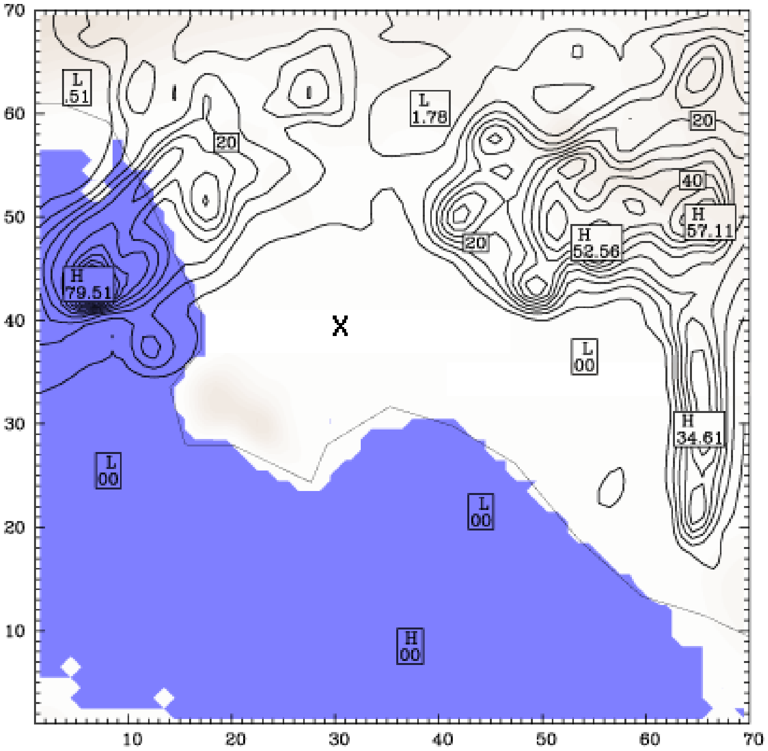

Fig. 10: As in Fig. 5, but for a run with simple ice microphysics. The "X" indicates roughly where the observed rainfall maximum was.

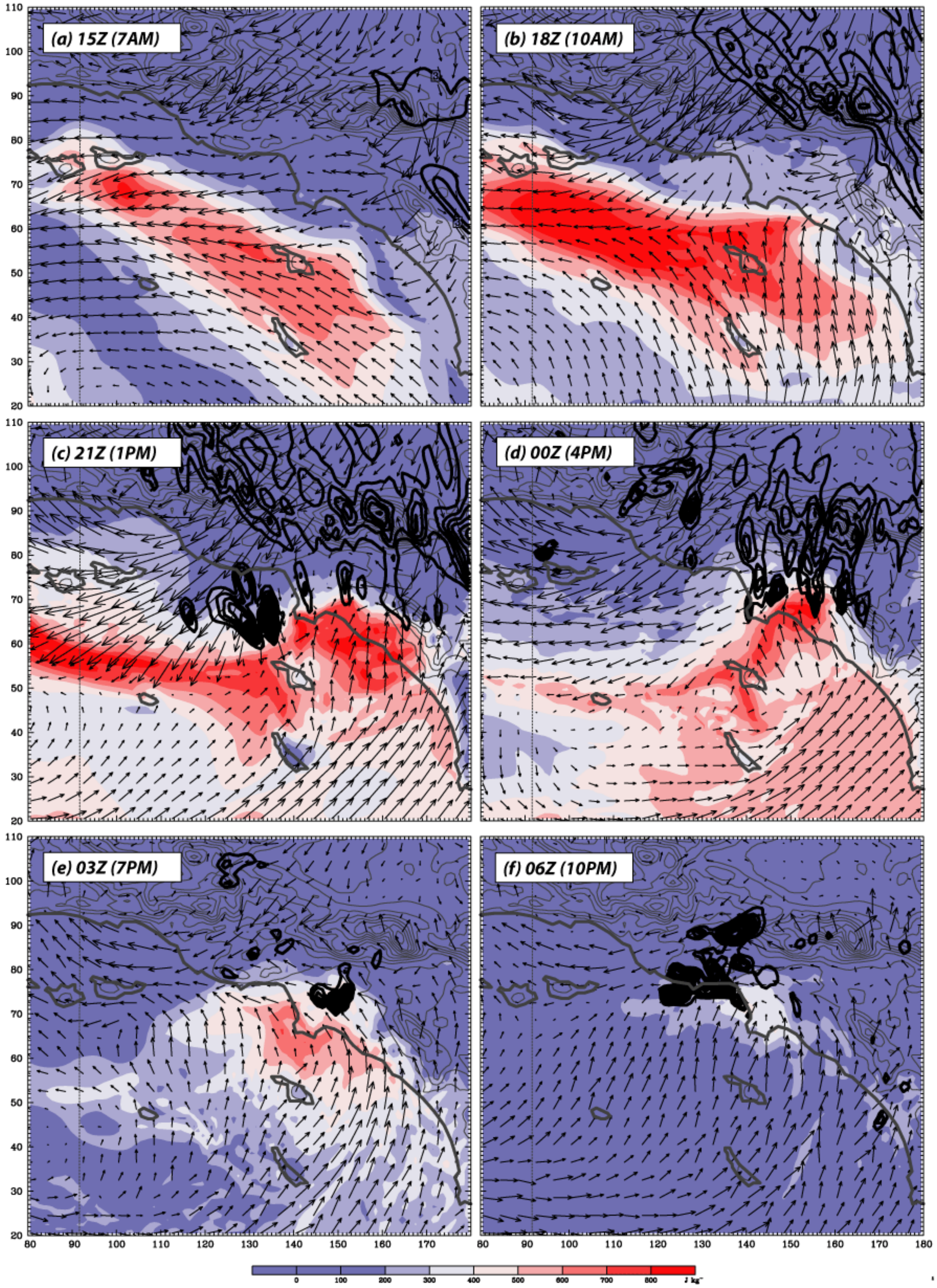

Fig. 11: CAPE distributions (colored field) and 10 m winds (every fourth gridpoint) from a 3 km WRF simulation at six times. Black contours show rainfall accumulations during previous *three* hours; 3 mm interval. 200 m topographic contours in grey. Only a portion of the domain is shown.

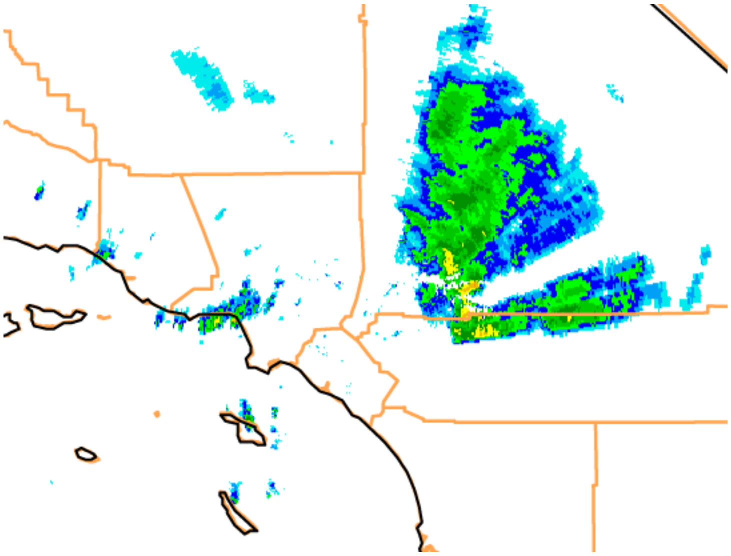

Fig. 12: KSOX radar image shown at 1904Z (11:04 AM). Note echoes along Malibu coast and in the Mojave Desert.

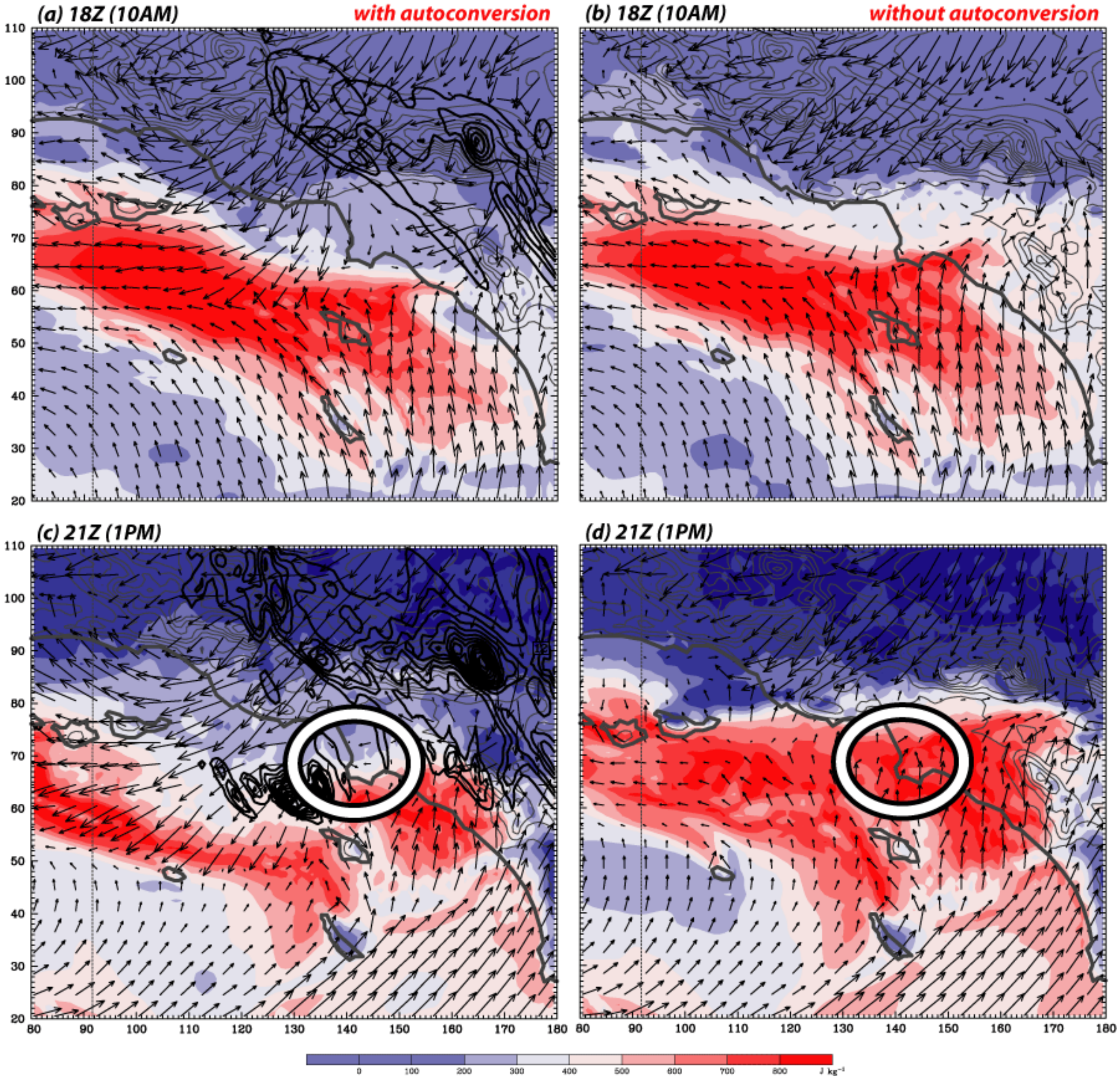

Fig. 13: As in Fig. 11, but for Kessler microphysics runs with and without autoconversion. Superposed ellipses help draw attention to the West LA area.