5B.3

SUPERCELL COLLAPSE

Leslie R. Lemon

University of Oklahoma,
Cooperative Institute in Mesoscale Meteorological Studies
Warning Decision Training Branch
Norman, Oklahoma

1. Introduction – Early work

While Browning (1965) made the first observations hinting at a supercell "collapse phase" (rapid hail size decrease, hook echo 'wrap up') it wasn't until Brown et al. (1973) and Burgess (1974) that additional observations more strongly suggested this collapse phase. These authors documented a right moving (to the right of the mean storm bearing winds) supercell storm that began as a non-severe multicellular storm that split into left and right moving counterparts. The right moving member took on a supercell storm structure with development of a mild-level Weak Echo Region (WER), a Bounded Weak Echo Region (BWER), and a low-level hook echo. Burgess showed that this structure began about 1.5 hours in advance of the most severe period in the life of the storm from 1700 (CST) to 1740. As a series of five tornadoes and a damaging wind swath began at 1700 the low-level hook echo was seen to "wrap-up" and disappear with echo top above (1700 – 1720). By the last time damaging wind and a tornado were occurring at 1740, the mid-level echo overhang had vanished; the Doppler radar mesocyclone was engulfed in strong echo (heavy rain and some hail) and the declining (by ~ 5 km) echo top was above. The echo top, WER and BWER collapse, and the wrap up of the hook echo took place as very severe weather was occurring. Burgess termed this the "collapse phase" for obvious reasons. Following collapse, the storm was non-severe and a member of a squall line.

Arguably, the most thoroughly documented tornadic storm at the time, the Union City, OK storm inflicted F5 tornadic damage near the small hamlet on 24 May, 1973. In a comprehensive report (Brown, 1976; Burgess and Lemon [1976, chapter 5]) it was shown that as the supercell echo top and the second BWER collapsed, surface tornadogenesis commenced at 1536 (CST) (Fig. 1a.). The tornado continued on as it enlarged and intensified.

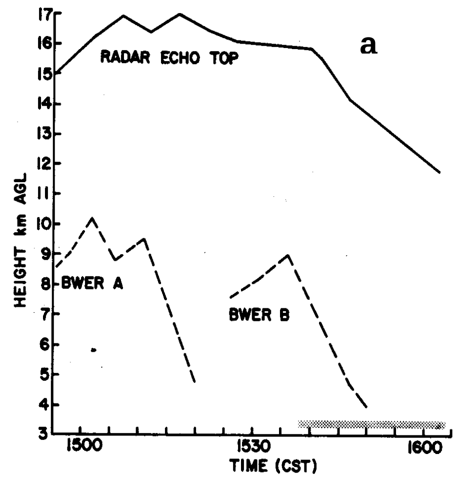
Simultaneously the echo overhang disappeared aloft and descended around the occluding mesocyclone along with the tornado and both migrated toward the rear of the storm (Fig. 1b). Doppler velocity data indicated that during the initial stages of reflectivity collapse the mesocyclone intensified and decreased in diameter and a TVS developed (Fig. 1c). The TVS developed aloft within the mesocyclone at 1517 and descended reaching the surface at 1536. As the tornado weakened the mesocyclone broadened, decreased in vertical depth, and also weakened (Fig. 1d). Similar to the Brown et al. and Burgess storm, at the conclusion of the collapse phase the Union City storm had again become a non-severe, multicellular storm and part of a squall line.

Two other collapsing supercells were studied during this period. Lemon (1977) documented a very large isolated supercell storm on June 18, 1973 in west central Oklahoma. This storm propagated slowly ~ 100^{o} to the right of the mean wind. The storm developed a WER around 1510 CST and began producing severe hail and then a BWER at 1610. Shortly after that 11 cm hail was produced at the surface by the storm. At 1630 the BWER began collapsing. Following BWER collapse and during F5 and F4 tornado production the storm summit began a slow but fluctuating decline and diminishing WER until the storm became non-severe and multicellular within a short line segment.

Corresponding author address: Leslie R. Lemon, CIMMS, WDTB, Norman OK, 73072; email: Les.Lemon@noaa.gov

In study of another storm Burgess et al, (1977) again documented a general decline in reflectivity structure and weakening while the mesocyclone amplified, increased in depth, and occluded while tornadoes occurred. Additionally the depth of the high reflectivity diminished during this period and VIL declined. This storm also became multicellular and non-severe.

To summarize these previous studies, during tornadogenesis and in some cases as the tornado increases in size and strength, the supercell collapse phase is revealed in reflectivity data by a rapid loss of supercell storm structure. In other words, the hook echo



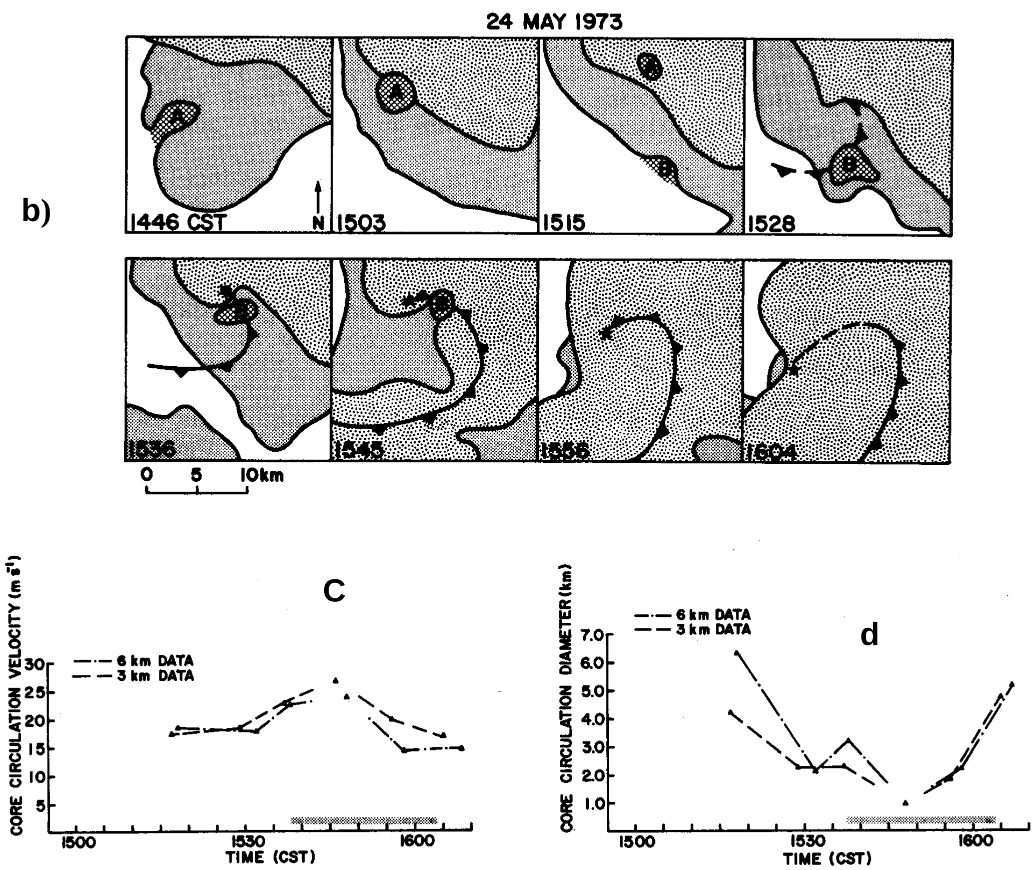


Figure 1. a) Graph of Union City storm top height, and maximum vertical extent of BWER's A and B as a function of time. Tornado duration on the ground shown by the stippled bar. b). Supercell changes on the right flank. Coarse stippling is low level echo, fine stippling is echo over hang. Star is tornado location with approximate surface gust front location. c) Core circulation tangential velocity at two heights above ground and d). mesocyclone core diameter changes with time. Tornado duration on the ground is shown as before. Figure after Lemon and Burgess, Chapter 8 (1976).

is seen to "wrap up" and disappear as the BWER fills and echo top descends and as the echo overhang collapses downward resulting in disappearance of the WER. Collapse of the echo overhang and therefore WER indicates that the storm has lost its ability to generate the echo overhang. That overhang existence is a direct manifestation of updraft intensity and divergence strength aloft. Thus, this is a strong signal of updraft weakening.

Overall, the echo top lowers, reflectivity weakens and the depth of the higher reflectivity diminishes as does VIL. As concluded above, these earlier studies found that this process is symptomatic of substantial updraft weakening leading to weakening of the entire storm. In fact, in the earlier studies, most of these collapsed storms became non-severe and multicellular as they were absorbed into squall lines. However, as we shall see here, only a portion of the supercell updraft may be affected in other cases.

We just considered the reflectivity manifestation of the collapse phase. Here we summarize the velocity indications of the same from these previous studies. As the reflectivity structure of the collapsing supercell is diminishing the velocity characteristics are undergoing amplification. The mesocyclone shear/rotational velocity increases and especially in lower levels. Contemporaneously the mesocyclone circulation may decrease in diameter. In some cases the mesocyclone depth initially increase only to decrease thereafter. With the amplification of the mesocyclone, a TVS may develop and become detectable within the mesocyclone aloft and/or in low-levels. These kinematic changes, where adequately observed, coincide with the occlusion of the low-level mesocyclone (Lemon and Doswell, 1979, Burgess et al., 1982). The overall reflectivity and updraft weakening may well be associated with RFD strengthening, and surface gust front occlusions. But the surprising thing is that not all supercells exhibit this phase, in fact, perhaps only a minority do. This begs the question as to why all supercells are not characterized by collapse with supercell occlusion if occlusion is as common as past studies suggest. None the less, the fact that some supercells undergo collapse with tornadoes and tornadogenesis has, as we shall see, important operational implications and may potentially impact on the warning forecaster and the warnings themselves.

This occlusion process leads to cutoff of low-level moist buoyant inflow and re-circulated RFD air. (In other words, air descends in the RFD tilting vortex lines downward and then this air converges into the incipient tornado circulation, rising again and stretching, resulting in tornadogenesis (Markowski, 2008). While Markowski (2000), and Markowski, (2002a, b) found that a positively buoyant RFD is necessary for tornadogenesis the collapse phase suggests that the bulk of this RFD air may differ thermodynamically and/or the volume of ascending air is decreased by a smaller updraft and restricted inflow. Thus, that re-circulated air may be significantly less buoyant or at least that air is not uniformly buoyant.

2. An Example of a "lesser" collapse – The Electra Storm

On 7 April 2008 a broad mid-level trough was anchored over the intermountain west with an impulse moving out over the high-plains of the US. Strengthening mid-level westerlies were associated with this impulse. At the surface, a lee Rocky Mountain trough and low pressure center was gradually deepening over the Texas and Oklahoma Panhandles as a shallow warm frontal system was lifting north over southwest Oklahoma. A Dry Line and triple point were located along the Red River near the Fredrick, OK radar with a strengthening low-level jet bringing upper 50 degree dewpoints into this area. This gave

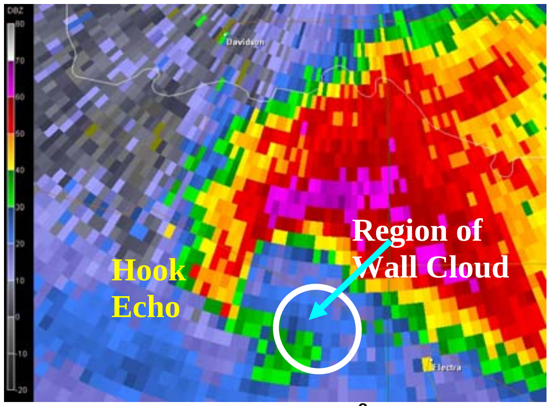


Figure 2. Base reflectivity (0.5^{o})image at 21:47 UTC from the KFDR radar in southwest Oklahoma. Hook echo and the area of the wall cloud in Fig. 3 are indicated.

rise to a supercell environment with a favorable hodograph, rapid destabilization, and a steep mid-level lapse rate. Mixed layer CAPE was near 2000 J/KG.

A series of four storms developed near the triple point and along the warm front between 20:00 (UTC) and 20:45. The most southern and western storm developed supercell structure by about 20:30 and quickly cut off inflow to, and merged with, the remaining three storms. By 20:40 only the large mature supercell remained (Fig. 2).

Figure 3. This photo was taken looking west toward the slowly rotating wall cloud from under the rain-free updraft base at about 21:50 UTC. A few thousand feet above this cloud base a tornadic vortex was descending toward the surface.

Storm chasers intercepted this storm and they observed a developing and rotating wall cloud. A few minutes before the previous radar image of Fig. 2, this photo of the wall cloud was taken (Fig.3). The wall cloud is the location of the updraft core and is tapping very moist contact layer air that originated in the storm precipitation cascade and forward flank downdraft region.

As shown earlier, shortly before the wall cloud photo, the reflectivity echo of the mature isolated supercell as seen in Fig. 2 and was only 14 miles south of the radar as it moved east-southeast at 20 kts. It exhibits a well defined hook echo bounding the inflow notch to the east. The area where the wall cloud is located is within the inflow notch and beneath the knob at the end of the hook as shown. The wall cloud itself is within but much smaller than this circle. Although not yet apparent, the collapse phase is already underway.

Using GR2Analyst software we can see the large 3-dimensional 45 dBZ echo isosurface surrounding the BWER within (Fig. 4a). Because of the proximity of the storm to the radar, the upper surface of this echo is truncated by the cone of silence but very likely extends upward to a height greater than 45 kft. Using the GR2Analyst velocity processing algorithm we can also see the TVS aloft above the hook echo and wall cloud. Note the TVS extends from a relatively short distance above the surface upward to near 30 kft. Thus, tornadogenesis is taking place.

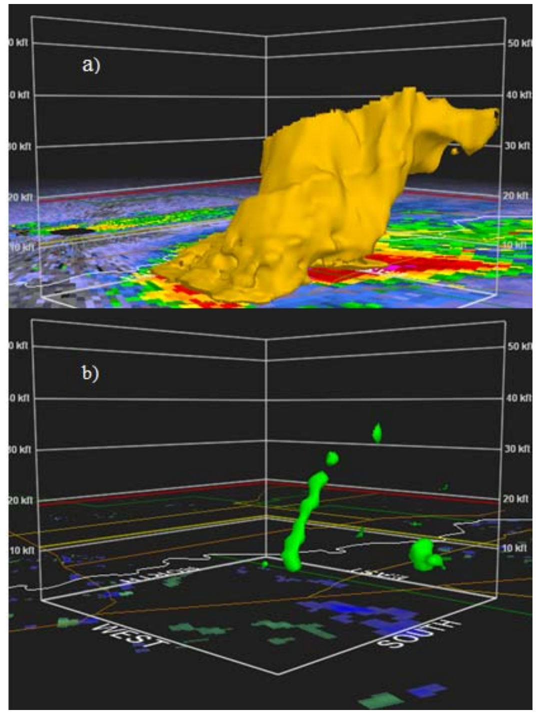


Figure 4.
GR2Analyst (http://www.grlevelx.com/) 3-D analyses at 21:47 of a) the 45 dBZ reflectivity isosurface and b) the velocity feature marking the location and vertical extent of the tornadic vortex.

Again, looking west in Fig. 5, the dark, rain-free, cloud base of the primary supercell updraft can be seen in the foreground and upper portion of the photo and is little changed. However, the wall cloud has now shifted back near the western edge of the primary updraft and the "clear slot" of the Rear Flank Downdraft is seen rotating from the west and south around to east side of the wall cloud (Lemon and Doswell, 1979, Markowski, 2002). And now, while the condensation funnel of the tornado is not in contract with the surface, the tornado vortex itself is and has been for about the last 4 minutes. Thus, the tornado is underway at the time of Fig.5 (22:03).

Figure 5.. The lowering of the wall cloud is seen looking to the west at 22:03. The left side of the wall cloud is illuminated by sun as the RFD "clear slot" wraps around the truncated tornado funnel.

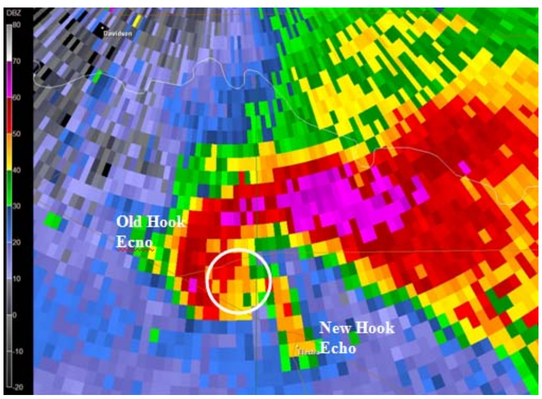


Figure 6. Supercell base reflectivity echo (0.5^{o}) at 22:03 UTC. The old and new hook echoes are labeled and the area of the wall cloud is encircled.

At the same time, 22:03, the low-level reflectivity echo is seen in figure 6. The shank of the previous (old) hook echo has pulled back northward from its previous storm-relative position. A new hook echo, now a "pendent echo" with the mature supercell is in the process of developing. The wall cloud and tornado are located approximately within the encircled area of Fig. 6 and the wrapping clear-slot seen in Fig. 5 is within but on the right hand (east side) of the circle.

Note that in Fig. 7 the images are constructed in such a way so as to exclude the larger portion of the mature supercell and include only the occluding and collapsing portion of the updraft. Aloft the old BWER has filled with echo while a new BWER is developing along with a new low-level hook

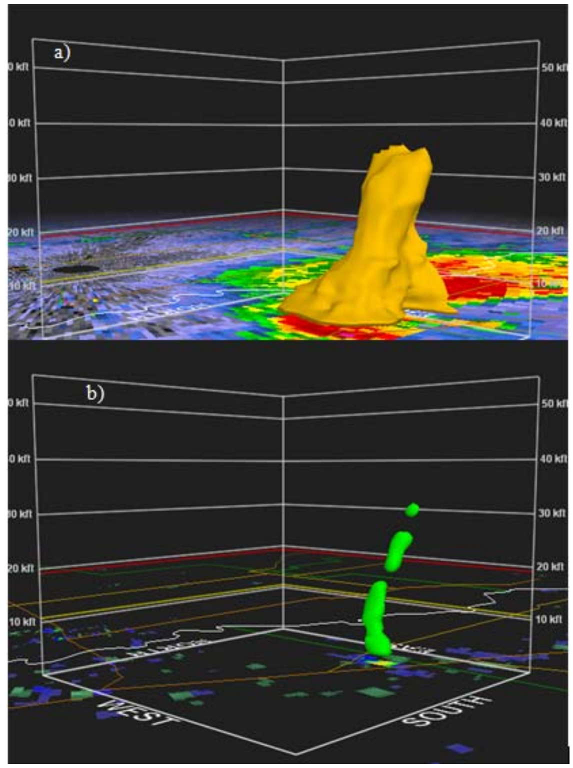


Figure 7. Same as Fig. 4 except for 22:03. Note that at this time the radar detected TVS extended downward to radar horizon.

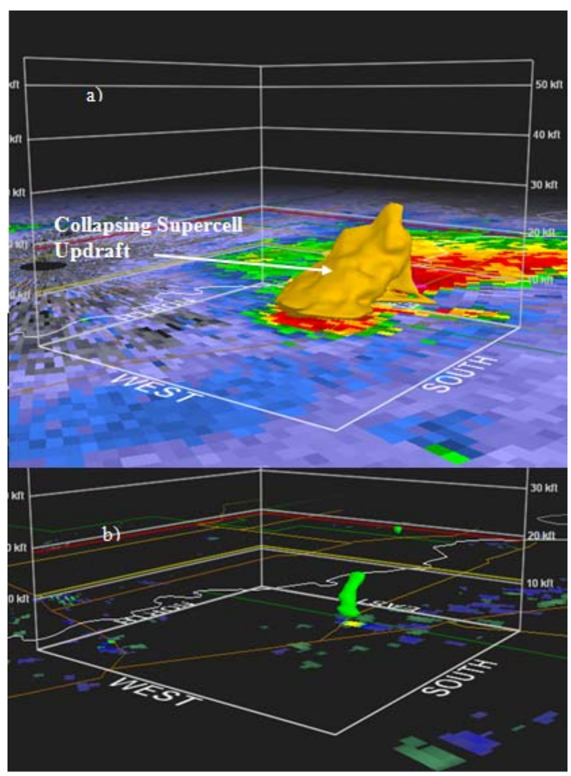


Figure 8. Same as Fig. 4 except for 22:07

echo here. There has occurred a substantial decrease in the size/volume of the hook and tornado associated 45 dBZ isosurface and the top of that portion of the supercell has fallen substantially to about 35 kft (Fig. 7a). The collapse is proceeding. We can also see that the surface tornado and TVS aloft still extends upward to about 30 kft as it moves north northeastward at 15 kts (Fig. 7b).

Just one volume scan later (Fig. 8) the upper limit of the 45 dBZ isosurface associated with the collapsing tornadic updraft has now lowered to ~ 24 kft. The TVS has also decreased in vertical depth to ~ 7 kft but the tornadic surface vortex is still present.

Finally, by the 22:11 volume scan what is left of the original supercell updraft is shown in Fig. 9a. and is little more than a remnant. It is a very small region of 45 dBZ extending upward to perhaps 12 kft! All that remains of the tornado is a rapidly weakening surface vortex with small vertical extension (detectable only in the base data).

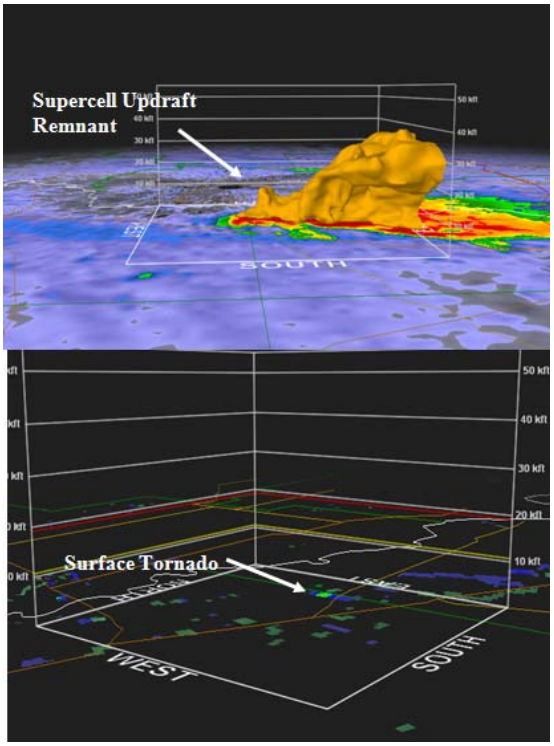


Figure 9. Same as Fig.4 except for 22:11 UTC. Notice the absence of a TVS aloft.

Note in Fig. 9a the perspective has changed in such a way to permit visualization of the rejuvenated but mature primary supercell updraft as well as the occluding and collapsing segment. Therefore more of the mature storm structure is visible with overhang and BWER (just beneath storm summit) now seen. The supercell continued moving east-southeast with slow weakening for the next 40 minutes but without additional tornadoes.

In this case study we began with a nearby and very well observed archetypical large mature supercell storm, mesocyclone, hook echo, Weak Echo Region, and Bounded Weak Echo Region. A Tornadic Vortex Signature or TVS developed aloft within the mesocyclone as the collapse began, signaled by a filling BWER and weakening portion of the supercell updraft. The hook echo, in a storm relative sense, moved northward and westward.

As the collapse proceeds, visually a clear slot is seen to develop and encircle the wall cloud and the low-level developing tornado which has now shifted, storm relative, to the west and north of the primary supercell updraft cloud base. As this is occurring visually, on radar the TVS aloft lowers toward the surface as the directly associated updraft shrinks. That tornado persists at or very near the surface for 12 to 15 minutes before dissipating. A new hook echo has developed and the original but rejuvenated supercell updraft continues moving east-southeast but without further tornadoes.

3. Operational Impact

What is the supercell collapse impact on operational applications? Radar reflectivity is the default base data display and often relied on for storm monitoring in the National Weather Service. However, the warning forecaster must be careful not to be mislead by the supercell reflectivity structural weakening. Sometimes during this process tornadogenesis may take place or an existing tornado may even enlarge and strengthen. The warning forecaster must be vigilant and continue a tornado warning if it has been issued unless and until both reflectivity and the velocity storm characteristics weaken or dissipate.

As shown earlier, the collapse may disrupt and weaken the entire storm updraft or it may affect only a portion of the updraft as with the Electra storm. During supercell updraft collapse, storm spotter reports are especially important. This is particularly true because the mesocyclone and TVS (if detected) often have reduced or decreasing vertical depth even when velocities in the mesocyclone may be amplifying in low-levels.

We have examined an aspect of some supercells called the collapse phase. The warning forecaster must be alert to the fact that not all supercells seem to exhibit this phase but some do and when it occurs the forecaster may be mislead unless both reflectivity and velocity products are carefully monitored.

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