PICTURE OF THE QUARTER

Nighttime Detection of Low-Level Thunderstorm Outflow Using a GOES Multispectral Image Product

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1. Introduction

Low-level thunderstorm outflow (hereafter referred to as LTO) boundaries can interact with the environment or with other storms in a variety of ways. Studies have shown that convection can be initiated, intensified, or weakened through interaction with an LTO boundary depending on local environmental conditions (Purdom 1976; Weaver 1979; Maddox et al. 1980; Wilson and Wilk 1981; Weaver and Nelson 1982; Wilson and Schreiber 1986; Weaver and Purdom 1995). The interface separating the environmental and LTO air masses can often be detected by Doppler radar (Wilson and Wilk, 1981). Although radar's ability to detect low-level boundaries is range limited, when boundaries are detectable by Weather Surveillance Radar-1988 Doppler (WSR-88Ds) they can be observed every 5–6 min.

Cloud lines generated along LTO boundaries can also be detected using satellite imagery. Those cloud lines, sometimes called arc clouds, frequently develop as a curved line of clouds along the boundary interface (Purdom 1973). In satellite imagery, stratiform low-level billow clouds (sometimes referred to as stable wave clouds) have also been observed to form at the top of the cold-air dome associated with the LTO. Geostationary satellite imagery can be used to observe the development and evolution of low-level cloud boundaries across a broad range of scales, including the mesoscale. Recently, the National Oceanic and Atmospheric Administration commissioned a new series of geostationary satellites with improved spatial and temporal resolutions, and while the previous generation Geostationary Operational Environmental Satellite (GOES) had two dedicated imaging channels, the new series has five. There is a 1-km resolution visible channel; three 4-km resolution channels centered at 3.9, 10.7, and 12.0 μm; and an 8-km resolution channel centered at 6.7 μm (Menzel and Purdom 1994). Also, with the new GOES, imagery is routinely available every 15 min over the continental United States (Hawkins 1997).

Both satellite and radar systems have inherent limitations that restrict their ability to detect LTO boundaries. Low-level thunderstorm outflow boundaries vary in depth but are normally only a few kilometers deep. With WSR-88D data, the lowest scan angle used operationally is 0.5°, limiting the detection of a 1-km-deep LTO boundary to a range of 80 km (NEXRAD Panel 1995). Satellite sensing of LTO boundaries also has limitations. Thunderstorm anvils may obscure the clouds produced by the LTO boundary, or the resolution of the instrument may not be sufficient to detect the clouds that form along the boundary. GOES visible imagery has the best resolution of the five imager channels but is limited to daytime use. Infrared (10.7 μm) window imagery may be used to detect clouds, day or night. However, there must be sufficient thermal contrast between the cloud and the surrounding clear ground for detection to be effective. This limitation is most noticeable at night when the earth's surface cools and low-level cloud and surface temperatures are similar. Low-level thunderstorm outflow boundaries can also be fol-

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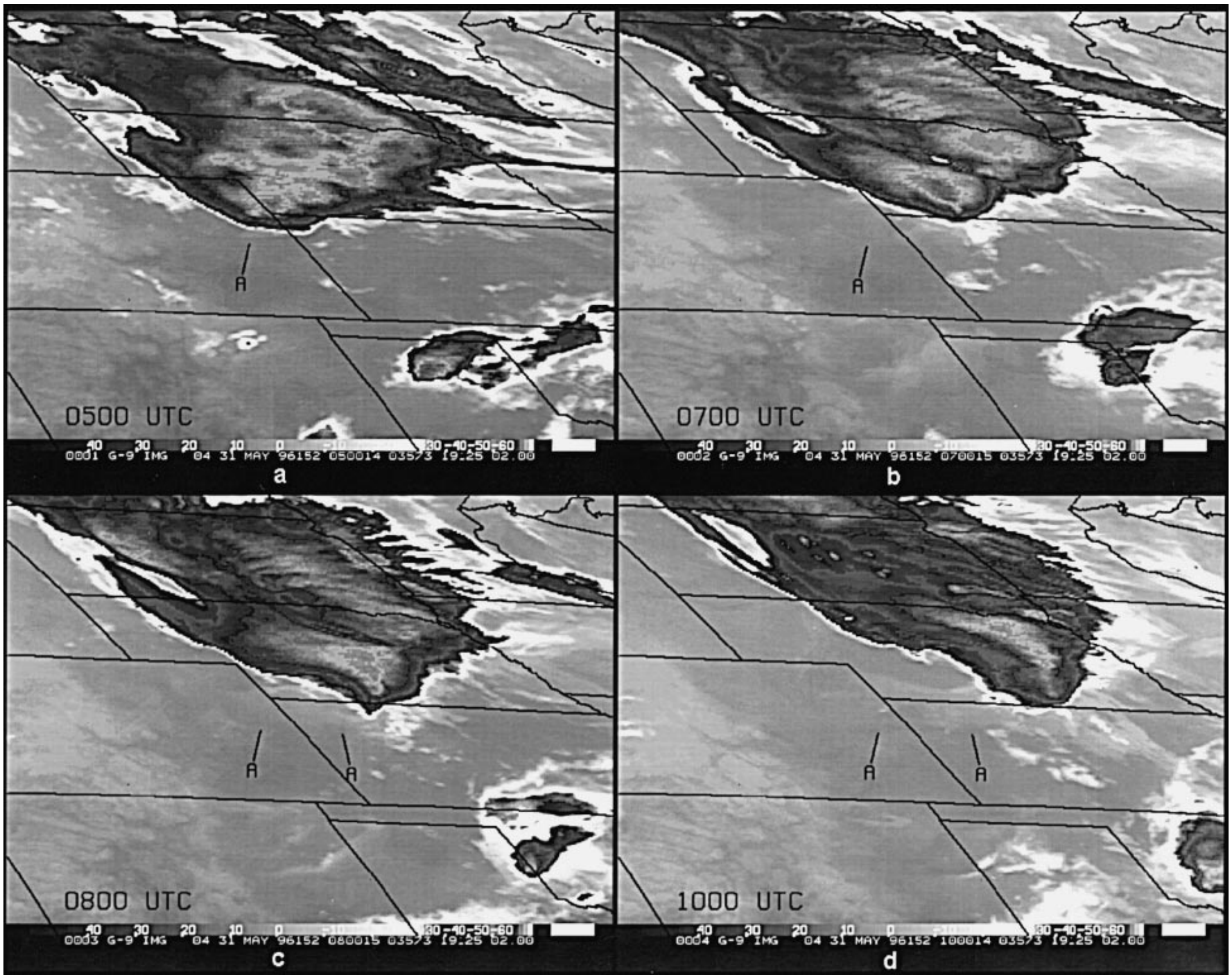

FIG. 1. The 10.7-μm imagery for the period 0500–1000 UTC 31 May 1996 showing a line of thunderstorms moving through Nebraska and South Dakota. The southern end of the complex is at the Nebraska–Kansas border at 0500 UTC. The leading edge of the rain-stabilized low-level thunderstorm outflow air at ''A'' (cf. to Fig. 2) is not clearly evident in these 10.7-μm satellite images because of a lack of thermal contrast between the clouds that formed along that boundary and the cool ground. The periods along the color bar at the bottom show the brightness temperatures in °C.

lowed at night using a multispectral image product derived from 3.9- and 10.7-μm imagery. This product is described in the next section.

2. Detection technique

The method for detecting nighttime LTOs discussed herein focuses on a multispectral image product made by subtracting the brightness temperatures at 3.9 μm from the brightness temperatures at 10.7 μm. Cloud-free scenes generally have very small brightness temperature differences between the two channels; however, this is not the case for liquid water clouds and thin cirrus clouds. Liquid water clouds have a positive brightness temperature difference because the emissivity at 10.7 μm is greater than at 3.9 μm. Thin cirrus clouds have a negative brightness temperature difference due to the Planck relationship between radiance and temperature; 3.9 μm is more sensitive than 10.7 μm to warmer radiances being transmitted through the cloud from below (RAMM 1996). Average differences for bare ground, low stratus, and cirrus clouds have been found to be $-0.4°$, $4.0°$, and $-14.2°$C, respectively (Nelson and Ellrod 1996). For very cold scenes, the 3.9-μm signal is dominated by noise (RAMM 1996); thus in the multispectral image product thick cirrus takes on a ''speckled'' appearance.

As will be illustrated in the next section, the multispectral image product is very effective in detecting liquid water clouds at night. It is similar to a GOES product discussed by Ellrod (1994) for the nighttime identification of low-level stratus and fog. This simple technique does not work during the day because the 3.9-μm channel also has a large brightness temperature component due to reflected solar energy (RAMM 1996).

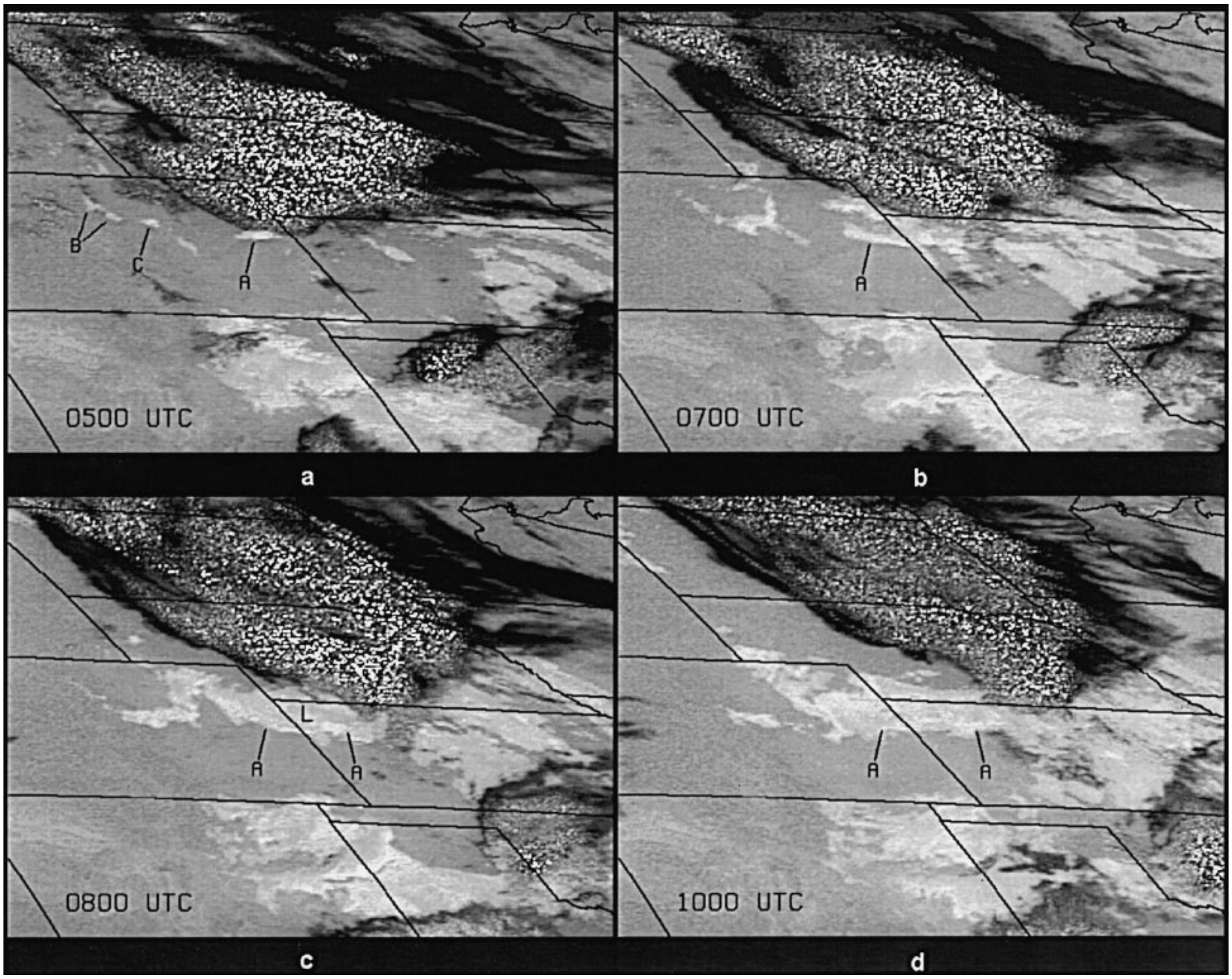

FIG. 2. The 10.7- and 3.9-μm multispectral image product of the thunderstorm complex in Fig. 1. The multispectral image product clearly shows liquid water clouds associated with the low-level thunderstorm outflow boundary at ''A'' and the stratocumulus cloudiness that developed to its north at ''L.''

3. Discussion of the example

At night, clouds that form along LTO boundaries are often shallow cumulus or stratocumulus clouds. These clouds are composed of liquid water droplets and, therefore, are detectable by the multispectral image product. Satellite imagery taken from *GOES-9* during the night of 31 May 1996 provides an excellent example of that capability. Figure 1 shows a sequence of 10.7-μm images, while Fig. 2 shows the corresponding multispectral image product. Inspection of the 10.7-μm images reveals a mesoscale convective system (MCS) with a large anvil and very cold cloud-top temperatures covering much of Nebraska and South Dakota. One might expect low-level thunderstorm outflow along the entire length of the line and should expect an arc cloud line to appear in northeast Colorado as the MCS moved east. However, low-level clouds are difficult to detect in the 10.7-μm imagery in that area. This is because the thermal contrast between the low clouds and the ground was insufficient for unambiguous cloud identification.

Inspection of the multispectral image product over northeast Colorado clearly shows an evolving arc cloud line with a stratiform region to its north. A black and white enhancement has been chosen for image analysis purposes. Negative differences (thin cirrus) are black, regions with little or no difference (ground) are gray, and positive differences (liquid water cloud) are shades of white. Where the multispectral image product is dominated by the noise at 3.9 μm (thick cirrus), the imagery is black and white 'speckled'. At 0500 UTC, a small area of liquid water clouds is apparent just south of the MCS in northeastern Colorado (A), a location where one would expect to find low-level cloudiness associated with thunderstorm outflow. Lines of low-level clouds can also be seen in central Colorado; those cloud lines formed along the sharply rising terrain of the foothills of the Rocky Mountains (B) and the northern edge of the Palmer Lake Divide (C). Between 0500 and 1000 UTC, the arc cloud line grew larger, and liquid water clouds developed in association with the LTO's cold pool; note the stable stratiform cloud (L) that develops north of the LTO boundary. This cloud deck expanded with time and is easily trackable using the sequence of images. The rain-stabilized air and LTO boundary played a key role in the development of severe thunderstorms in central Kansas later in the day. Some of those storms were tornadic. Utilization of the multispectral image product in this particular case would have made it possible to focus attention on the boundary early in the convective forecast cycle.

4. Final remarks

Imagery from the new GOES satellites provides an effective tool for the detection and monitoring of LTO boundaries during both day and night. These boundaries are not only important to later convective development, but also in the nowcasting of wind shifts, low-level wind shear, and changes in temperature and dewpoint temperature. Visible imagery can be used during daylight hours, while the multispectral image product extends that capability to nighttime situations. There is still a problem of detection when anvils grow large, but in many severe weather situations the environmental shear advects anvils away from the regions of greatest interest.

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