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Interpretation of GOES Water Vapor Imagery and Its Application to Forecasting Thunderstorms

[Editor's Note - The following paper was prepared for the Third International Conference on the Aviation Weather System, 29 January - 3 February 1989 at Anaheim, California. It provides an excellent review of the utility and characteristics of water vapor imagery. This paper then details a case study that illustrates how water vapor imagery can provide important information that may not be obvious from the standard analyses or other satellite imagery. The study is applicable to the Western Region and should especially be useful as a training exercise for those WSOs which have recently acquired the PC-based Satellite Information Processing System (SIPS).]

INTERPRETATION OF GOES WATER VAPOR IMAGERY AND ITS APPLICATION TO FORECASTING THUNDERSTORMS

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1. Introduction

The overall utility of GOES satellite imagery in weather analysis and short-term forecasting is well established. In an age of rapid development and implementation of new data collection systems, operational satellite imagery remains one of the most powerful tools available to the forecaster. GOES satellites have been providing frequent reflected-visible (VIS) and thermal-infrared (IR) images for over thirteen years. These familiar image types are now commonly viewed on video monitors in still and looping modes.

Weather forecasters have gained much skill and insight using VIS and IR imagery in determining current weather conditions, inferring on-going weather processes, locating synoptic and mesoscale features, and verifying numerical forecast model initializations and forecasts. Animation and color-enhancement can dramatically increase the utility of the imagery, providing spatial resolution and temporal continuity that is not as readily recognized by flipping through a stack of hard-copy pictures. Subtle small-scale weather features become more apparent when enhanced and seen in motion. Advanced interactive weather data systems, such as the Program for Regional Observing and Forecasting Systems (PROFS) prototype DAR^{3}E system (Bullock et al., 1988), have further increased the value of the imagery by remapping it to a common projection with radar data, operational anaylses, and numerical model output so that they can be overlaid and compared.

GOES spacecraft launched after 1980 have on board a Visible and Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS). The VAS gathers radiation in up to 12 infrared channels in addition to the visible band. One of these channels, the 6.7-micrometer wavelength (channel 10), is highly absorbed by middle and upper tropospheric water vapor. Data derived from this wavelength (often referred to as water vapor channel imagery) have been somewhat under-utilized due to inherent interpretation problems.

Most of the work done with water vapor imagery has been with interpretation of large-scale upper-level flow features. For example, certain signatures and patterns have been related to zones of middle and high level turbulence (Ellrod, 1985) and jet stream maxima (Ramond et al., 1981). This imagery has also been found to be very useful in identifying and evaluating the location, strength, and development stage of middle and upper-level vorticity maxima (Funk, 1986). Some preliminary studies have shown relationships between dark band ("dry slot") signatures in the imagery and the development of strong thunderstorms (Rodgers et al., 1988; Beckman, 1987; Petersen and Mostek, 1982). These studies can be expanded and applied to 0-6 h thunderstorm forecasting with some success. We feel that in certain situations, water vapor imagery contains information that, when incorporated with careful diagnosis, will help improve lead time and reduce geographic coverage of convective outlooks.

In this paper, we will discuss the characteristics of 6.7-micrometer imagery, then offer an interpretation and application of this imagery in regional-scale forecasting on a "garden-variety" thunderstorm day in northeast Colorado.

2. Characteristics of 6.7-micrometer Imagery

If we treat air molecules as blackbody radiators, spectral radiance (the energy per unit time per unit area per unit solid angle per unit spectral interval) emitted by these molecules is described by Planck's Law. This means that at a given wavelength, the spectral radiance increases as the temperature of the air increases. But radiation at the 6.7-micrometer wavelength is absorbed by water vapor, and the presence of water vapor modulates the amount of radiation that is transmitted. For an atmosphere viewed from geostationary orbit, the radiation sensed at the satellite is the integrated radiance between the satellite and the surface; the radiation at any level is emitted according to Planck's Law, and absorbed by the distribution of water vapor along the path.

The radiance sensed at the satellite is converted to a "brightness temperature", based on a standard-atmosphere weighting curve. The imagery is produced from the field of brightness temperatures after some smoothing of the data. Warmer brightness temperatures, represented by darker shading in linearly enhanced imagery, generally indicates an absence of middle and upper tropospheric moisture. Increasingly lighter shading indicates colder brightness temperatures, therefore, the presence of one or more layers of mid and upper-level moisture. Operational users of channel 10 data assume a moisture detection capabitity based on the standard-atmosphere weighting curve for the 6.7 micrometer wavelength, which is sensitive to water vapor in the layer roughly between 24-62 kPa, centered at 40 kPa.

As might be imagined, the same radiance at the satellite could arise from very different temperature and moisture soundings. Because of this, determining the precise altitude or quantity of moisture detected by the 6.7-micrometer channel is not possible operationally, at this point.

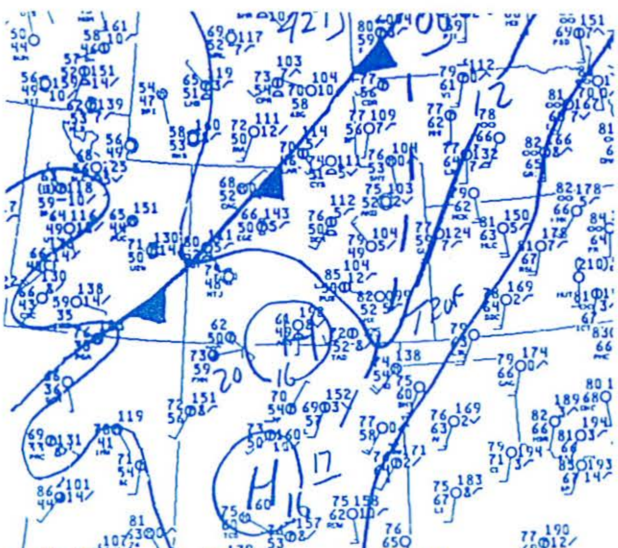

Figure 1. Surface analysis for 1500 UTC, 22 July 1987.

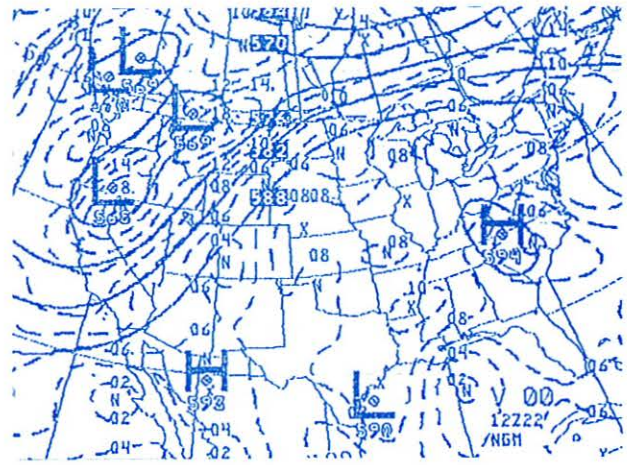

Figure 2. NGM initial analysis of 50 kPa heights and vorticity for 1200 UTC, 22 July 1987.

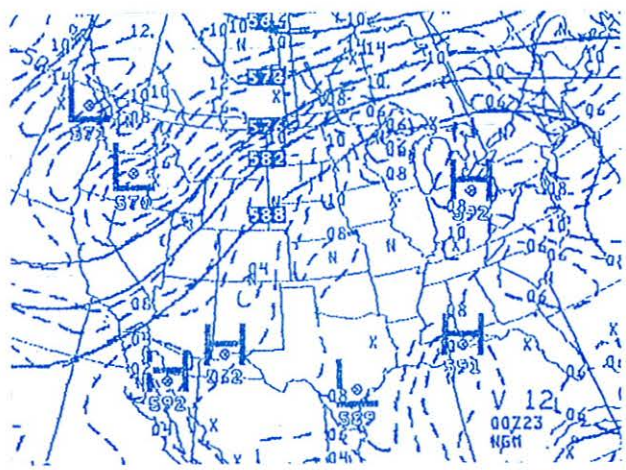

Figure 3. NGM 12-h forecast of 50 kPa heights and vorticity valid 0000 UTC, 23 July 1987.

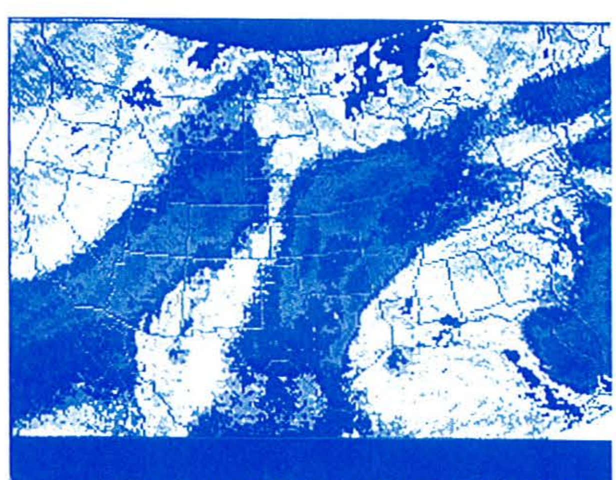

Figure 4. Enhanced national-sector water vapor image for 1600 UTC, 22 July 1987.

3. Forecast Application

The utility of water vapor imagery in regional-scale forecasting is illustrated by the case of 22 July 1987. Space does not allow us to reproduce all the products used to develop our forecast. However, the situation can be described as follows. The conventional large-scale data from 1200 UTC 22 July 1987 indicated a very low likelihood that the Denver/Boulder region would experience thunderstorms. The passage to the northeast of a minor short-wave trough during the previous night left the region under the influence of a broad, weak lee trough at the surface (Fig. 1), accompanied by light southwesterly (downslope) surface winds at Denver, veering slightly in the lower troposphere. A very warm 50-kPa temperature (-5 °C) and 70-kPa inversion indicated suppressed conditions. A weak short-wave ridge, with implied subsidence, was propagating over the area from the southwest. Information from a radiometric thermodynamic profiler at Denver showed a downward trend in precipitable water, and with a cloudless sky, the surface dewpoint temperatures were expected to mix out from the high 40's to low 40's (°F). The NGM initial analysis of 50-kPa heights and vorticity from 1200 UTC 22 July (Fig. 2) showed eastern Colorado under weak southwesterly flow with negative vorticity advection (NVA). The 12-h forecast of 50-kPa heights and vorticity valid at 0000 UTC 23 July (Fig. 3) indicated that the region would remain under NVA and light southwesterly flow through the afternoon.

Examination of the water vapor imagery revealed a subtle feature approaching Denver that changed this forecaster's assessment of thunderstorm potential for the day. By viewing an eight-frame hourly loop of national-sector water vapor images (see, for example, Fig. 4), with 50, 30, and 25-kPa plots overlaid, details in the data that might have otherwise been overlooked could be related to a discontinuity in the water vapor distribution. A regional-sector image at 1600 UTC (Fig. 5) shows a narrow swath of moisture, bracketed on the east and west by drier air, extending from New Mexico northward through extreme eastern Colorado and western Kansas. A "bulge" in the moisture is evident in western New Mexico, and animation of the imagery showed a northeastward propagation of this feature. The morning upper-air charts revealed strong south-west winds at 30, 25 and 20 kPa at Grand Junction and Winslow (Denver's sounding terminated just above 40 kPa), and significant speed shear between Winslow and Albuquerque (see Fig. 6). This wind information, added to the apparent increased or upwelling moisture over

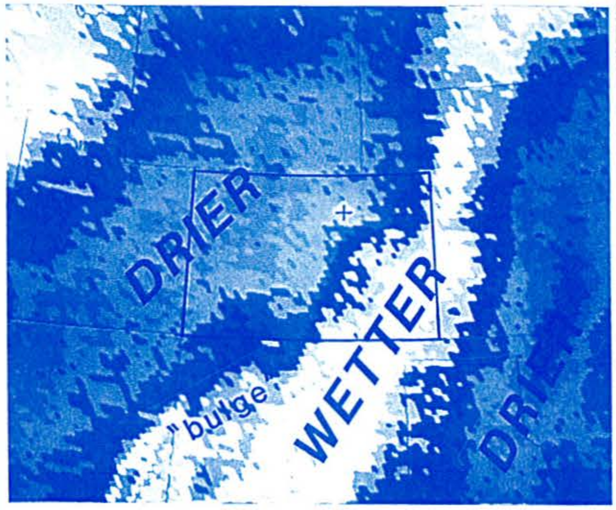

Figure 5. Enhanced regional-sector water vapor image for 1600 UTC, 22 July 1987. Colorado is outlined, and the cursor locates a position approximately 40 km NE of Denver.

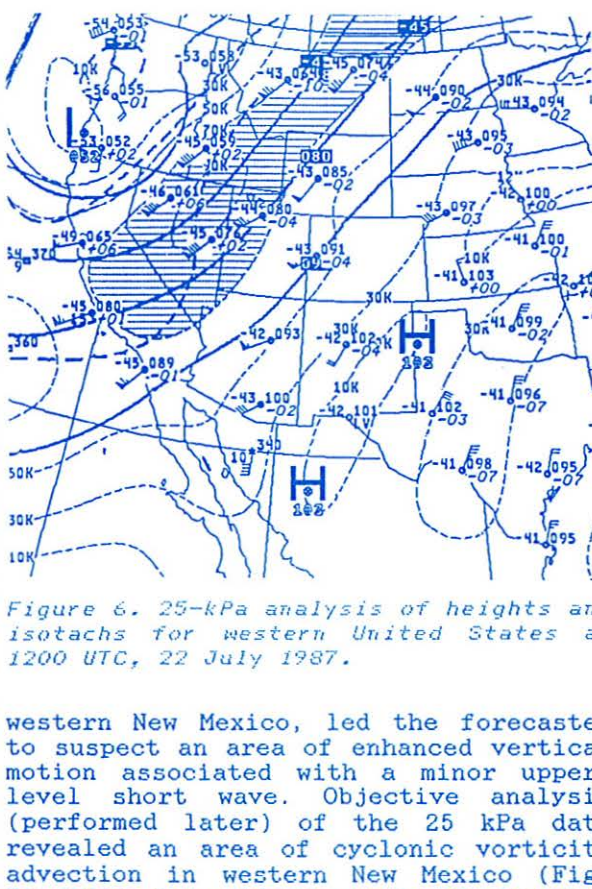

Figure 6. 25-kPa analysis of heights and isotachs for western United States at 1200 UTC, 22 July 1987.

western New Mexico, led the forecaster to suspect an area of enhanced vertical motion associated with a minor upper-level short wave. Objective analysis (performed later) of the 25 kPa data revealed an area of cyclonic vorticity advection in western New Mexico (Fig. 7). With favorable upper-level dynamics approaching Denver, where the sounding showed conditional instability, the possibility of late afternoon thunderstorms became more distinct. Figure 8 shows the moisture discontinuity had propagated north into south-central Colorado by 1800 UTC and by 2130 (3:30 pm MDT) had advanced into northeast Colorado (Fig. 9).

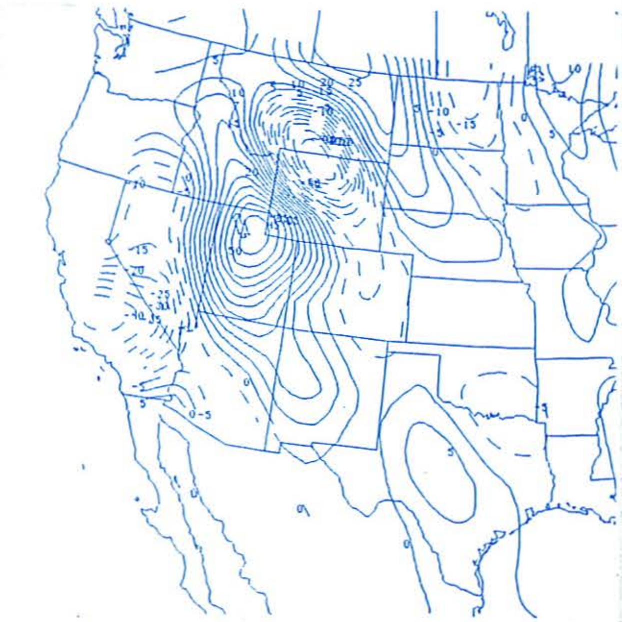

Figure 7. Objective analysis of advection of 25-kPa geostrophic vorticity by the geostrophic wind at 1200 UTC, 22 July 1987.

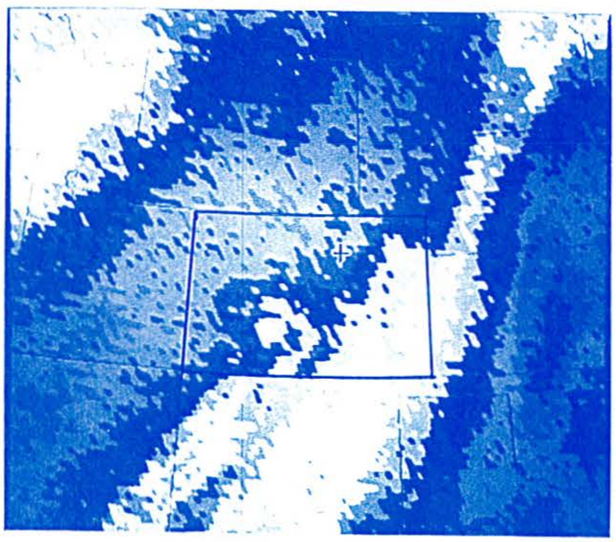

Figure 8. Same as Figure 5, but for 1800 UTC.

Thunderstorms formed along the Colorado foothills during the afternoon. Some intensified, drifted eastward through the Denver area, and produced local rain accumulations up to 12.5 mm. The arrival of the leading edge of the moisture feature into northeast Colorado coincided with the increased thunderstorm activity. On a day when the conventional morning data indicated little chance of significant thunderstorms in northeast Colorado, scattered, significant storms did develop, impacting a major metropolitan area at afternoon rush-hour (Fig. 10).

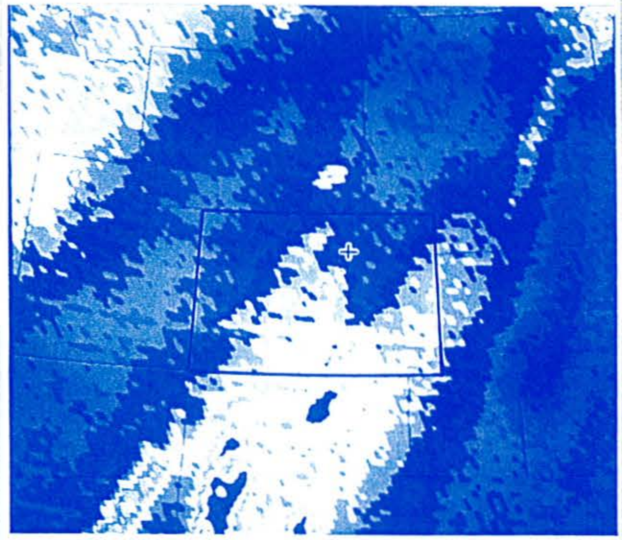

Figure 9. Same as Figure 5, but for 2130 UTC.

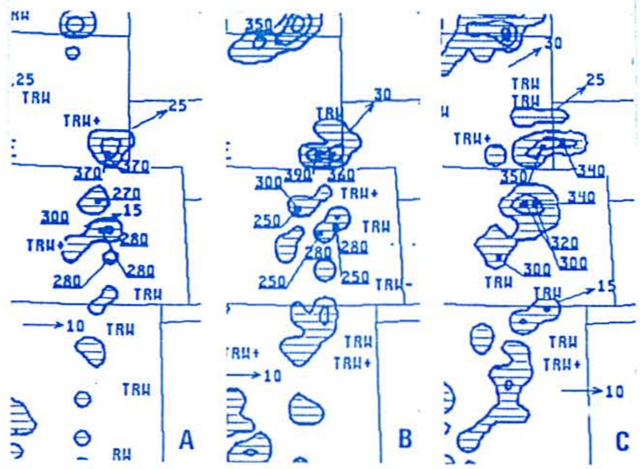

Figure 10. Radar composite charts for (A) 2130 UTC, (B) 2230 UTC, and (C) 2330 UTC, 22 July 1987.

The 25-kPa analysis from 0000 UTC 23 July clearly shows an upper-level jet streak (Fig. 11) and associated vorticity advection (Fig. 12) passing into northeast Colorado. We surmise that secondary vertical circulations associated with this jet streak were transporting mid-level moisture upward, and that the "bulge" in the upper-level humidity distribution clearly indicated this area of enhanced vertical motion. Furthermore, this feature could be identified and its movement extrapolated hours before convection began. The mesoscale dynamics responsible for the moisture discontinuity signature were further manifested by severe thunderstorms over the Dakotas later that night and flash floods in Minneapolis the following day.

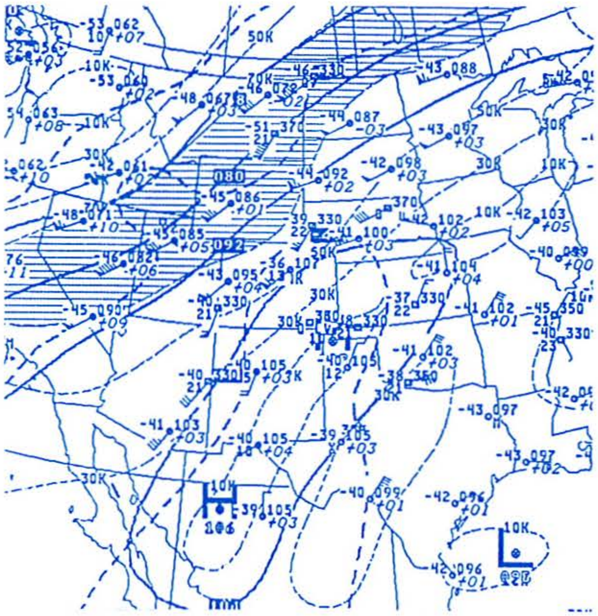

Figure 11. 25-kPa analysis of heights and isotachs for western United States at 0000 UTC, 23 July 1987.

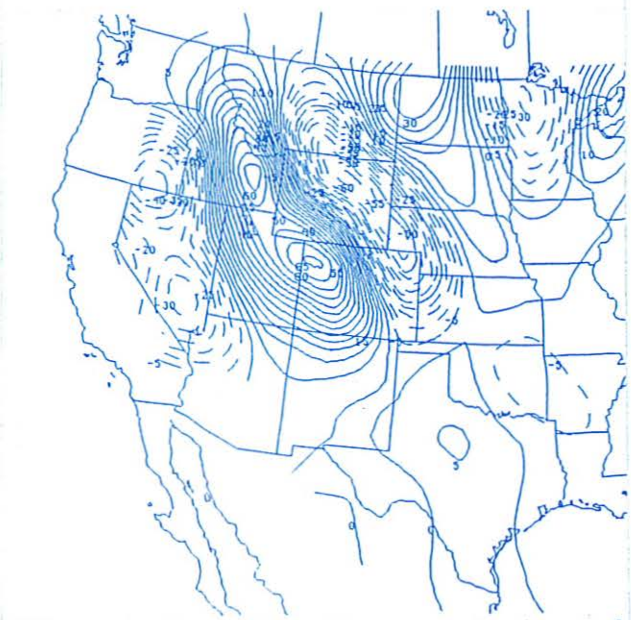

Figure 12. Objective analysis of advection of 25-kPa geostrophic vorticity by the geostrophic wind at 0000 UTC, 23 July 1987.

4. Concluding Remarks

In this case, Denver was in a generally favorable thunderstorm regime, with a large-scale trough to the west and a conditionally unstable morning sounding, but the data and NGM guidance seemed to show a quiescent day. The water vapor pictures were valuable in two ways. First, the moisture discontinuity observed in the hourly loop flagged an important upper-level feature. Once the dynamic feature was identified and the forecaster formed a conceptual model of the day's weather, the imagery then allowed half-hourly updates to verify or modify the conceptual model.

Describing quantitatively what role the water vapor signature mechanisms played in the development of vigorous thunderstorms that afternoon would be very difficult, especially since the timing coincided with maximum afternoon heating over elevated, complex terrain. However, the information contained in the animated, enhanced water vapor imagery led to a higher thunderstorm probability forecast. The higher probability was based on experience viewing water vapor loops and carefully relating subtle signatures to the standard synoptic data, then to subsequent weather. This straightforward empirical technique involves viewing the water vapor as a tracer of dynamic features, and therefore, in this context, the exact height or quantity of the vapor is almost irrelevant. Even though quantitative interpretation is ambiguous and operationally impractical, qualitative use in forecast applications is still of significant value.

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