Combined Atmospheric Sounding/Cloud Imagery—
A New Forecasting Tool

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Abstract

A method for displaying sounding and cloud information in a composite image is described. Examples are shown to illustrate how a forecaster may use a time sequence of these images to monitor changes in atmospheric moisture and stability antecedent to convective weather and at the same time monitor the cloud developments resulting from these atmospheric moisture and stability tendencies. The image products are now being produced in real time at the University of Wisconsin for an assessment of their operational utility as a part of the NOAA Operational VAS Assessment (NOVA) program. It is likely that the sounding/cloud imagery product will be available to all forecast centers in 1986, after the VAS data acquisition and processing system becomes fully operational.

1. Introduction

The VISSR Atmospheric Sounder (VAS) on the Geostationary Operational Environmental Satellite (GOES) series of satellites provides atmospheric water vapor and temperature sounding information with 7 km spatial resolution. Because the VAS operates in the infrared portion of the spectrum, the sounding information with 7 km spatial resolution. Because the VAS operates in the infrared portion of the spectrum, the sounding information is compromised by cloudiness to a degree dependent upon the cloud height and amount. Experience has shown that useful soundings can be achieved in cloud-free or low-level cloud overcast conditions (Smith, 1983; Anthony and Wade, 1983; Hayden et al., 1984). Breaks in sounding coverage due to clouds cause errors in objectively produced contour displays of the sounding data and consequently limit their utility for objective weather forecasting. Also, since the cloudiness can undergo rapid evolution and movement in convective or fast-moving frontal situations, it is very difficult to achieve time continuity of objective analyses of the one to three hourly interval VAS sounding data. Large gaps in the coverage of vertical soundings from VAS will occur across areas of extended middle- and high-level cloudiness. For the numerical analysis/forecast application of VAS soundings, the cloud gap problem can be alleviated through the use of ancillary data—for example, cloud and water vapor motion tracer winds (Le Marshall et al., 1984), and/or by imposing physical constraints on the space and time structure permitted in the analysis (Lewis et al., 1983). A forecast field can also be used as a control of the analysis across data void regions. For real-time subjective use of the sounding information, for example, for nowcasting convective weather, a high-resolution image presentation is more appropriate than a low-resolution contour analysis. Chesters et al. (1983) devised a technique for creating images of low-level moisture from VAS window and water vapor channel data. However, there were blanks in their images where clouds existed. For general forecast use, a presentation technique is required that: 1) preserves the full resolution of the data; 2) does not display any artificial information, as might arise from an objective analysis across data sparse regions; and 3) provides a real time image display of the data. To achieve such a nowcasting product, a scheme was devised to: 1) produce 7 km resolution sounding information as part of the current VAS sounding production process; 2) put the sounding values in an image (i.e., grey scale) format and combine it with the cloud image information provided by the VAS infrared window (11 µm) radiance observations; and 3) enhance the combined sounding/cloud image in such a manner that the cloud portion of the image can be easily distinguished from the atmospheric sounding portion of the image. The technique and two illustrative examples of the resulting product as produced on the Man-computer Interactive Data Access System (McIDAS) at the University of Wisconsin (Suomi et al., 1983) are described here.

2. Sounding determination

The retrieval system is set up to produce soundings with a resolution and spacing of about 80 km. This is achieved by inspecting the radiances for an 11 X 11 array of 7 km fields of view, eliminating the cloud-contaminated ones, and averaging the remaining ones to achieve a cloud-filtered, spatially averaged set of spectral radiances for each sounding area of 80 km resolution.

The solutions for the temperature \( T \) in Kelvin and water vapor mixing ratio \( q \) can be written in the form

\[
T(p) = T^0(p) + \sum_{j=1}^{M} a_j(p)[T_b(\nu_j) - T^0_b(\nu_j)]
\]

and

\[
q(p) = q^0(p) + q^0(p) \sum_{j=1}^{M} \beta_j(p)[T_b(\nu_j) - T^0_b(\nu_j)].
\]

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where $p$ is pressure and $M$ is the number of VAS spectral channels (12). The $\alpha(p)$ and $\beta(p)$ retrieval coefficients are in this case solely dependent upon the atmospheric transmittance, its dependence on water vapor, the Planck radiancy dependence on temperature, and the expected errors of the radiance observations (Smith and Woolf, 1984). The retrieval coefficients are obtained by matrix inversion; the transmittance and Planck radiances ($T_A$) are specified by the initial profiles, $T^0(p)$ and $q^0(p)$.

For the purpose of the sounding image generation the retrieval coefficients, $\alpha_1$ and $\beta_1$, are assumed to be representative of each individual VAS field of view. Consequently, individual field of view soundings are produced by applying the 80 km area average retrieval coefficients to the individual cloud-free field of view radiances. In this case, $T^0(p)$, $q^0(p)$, and $T_A^0(u)$ are specified as the area average retrieval values and the area average brightness temperature observations. As most of the computational work is performed in achieving the retrieval coefficients and not in their application, the production of individual retrievals does not result in a significant increase of computer time in the sounding retrieval process.

3. Combined sounding/cloud image generation

Once the soundings are produced for each individual cloud-free field of view, any desired sounding product (e.g., total precipitable water) can be combined with the 11 $\mu$m window radiance observed in the cloud-contaminated fields of view. The sounding value is allocated to the first half of the dynamic range of the grey scale used for the image presentation, whereas the 11 $\mu$m cloud radiance is allocated to the second half of the grey scale range. The sounding portion of the grey scale is then color-enhanced in order to distinguish the clear atmosphere characteristics from the cloud features.

Fig. 1 (a) is presented as an illustration of the image generation. Shown on the right side is an 11 $\mu$m (VAS band 8) infrared cloud image for 1400 GMT on 10 April 1984 over central Texas. On the left is a plot of the 80 km resolution total precipitable water vapor values corresponding to the soundings derived from the 11 $\times$ 11 field of view radiance arrays. Total precipitable water vapor values corresponding to the individual cloud-free fields of view are denoted by the colored resolution elements, with the color scale given at the bottom of the image. The resolution elements corresponding to cloud-contaminated fields of view have been filled with the 11 $\mu$m radiance values, and this portion of the grey scale has a black and white enhancement. Although the individual field of view values appear noisy due to the fact that the single field of view radiances are noisy relative to their area average values, coherent small-scale features can be seen, particularly in regions where strong horizontal gradients exist.

4. Sample results

Two of the sounding/cloud imagery products that have been found to be useful for monitoring convective storm developments are the total precipitable water vapor and the total-stability index. The total precipitable water vapor ($U$) is calculated using the relation

$$U = \frac{1}{g} \int_0^p q(p) dp,$$

where $g$ is the acceleration due to gravity and $p$ is the atmospheric surface pressure. The total-stability index ($TT$) is given by

$$TT = T_d(850) + T(850) - 2*T(500),$$

where 850 and 500 refer to the 850 mb and 500 mb pressure levels, respectively. The dewpoint temperature ($T_d$) at 850 mb is calculated from the 850 mb mixing ratio using Teten's formula. $T$ is the air temperature.

Fig. 1 (b and c) shows images of total precipitable water vapor/cloud and total-totals/cloud images for 10 April 1984 at three hour intervals. The contours displayed correspond to an objective analysis of the 80 km resolution retrievals, using the Barnes scheme (Barnes, 1964), resident on the McIDAS system. As can be seen, a large convective system located over Nebraska, Oklahoma, and northern Texas associated with an upper-level cut-off low is moving eastward during the day. The precipitable water/cloud imagery (b) shows a maximum water vapor concentration over eastern Texas, propagating eastward with the convective system. Strong horizontal gradients of moisture can be seen to the east and west of the storm complex. The area extent of high moisture values over Texas diminishes somewhat as the system moves eastward. At 1700 GMT the moisture imagery indicates that the largest moisture values are over the Texas-Louisiana border. On the other hand, the atmospheric stability imagery (c) shows destabilization occurring during the day across eastern Texas and western Louisiana. Severe storm stability conditions (total-totals in excess of 60°C) exist in this region at both 1700 and 2000 GMT. The destabilization is presumably due to increases in the temperature lapse rate of the lower troposphere, since the water vapor is steady or decreasing in magnitude during this period, as shown in Fig. 1. Both the stability trends and the location of the maxima total-totals index values are in good correspondence to the afternoon and early evening (2000–0200 GMT) severe weather reports as shown in Fig. 1.

Another situation is shown on the cover for 14 May 1984. In this case at 1100 GMT there is a small total precipitable water maximum over Arkansas along a cold front stretching across the southeastern United States in a northwest flow aloft situation. This area of high water vapor concentration extends eastward with time and increases in magnitude during the day with isolated values in excess of 45 mm occurring along a narrow line stretching from eastern Mississippi across central Alabama and Georgia and into southern South Carolina. The stability of the atmosphere (see upper left panel of cover illustration) decreases dramatically over the southeastern states, with severe weather instabilities (total-totals in excess of 60°C) occurring over southern Alabama, southern Georgia, and southern South Carolina at the 1400 and 1700 GMT VAS sounding observation times. Once again areas of maximum instability and the trends in both moisture and stability provide good indications of the potential for...
Fig. 1. (opposite page) Side-by-side display (a) of VAS total precipitable water vapor/cloud imagery (left) and VAS 11 μm imagery (right) at 1400 GMT on 10 April 1984 over east central Texas. Plot of total precipitable water vapor values from 11 × 11 field-of-view VAS retrievals (sample boxes shown). Time sequence of VAS total precipitable water vapor/cloud imagery (b) and VAS total-totals/cloud imagery (c) with contours of the 11 × 11 field-of-view average retrieval values over the central United States on 10 April 1984 at 1100, 1400, 1700, and 2000 GMT. Severe weather reports (T = tornado, H = hail) from 2000 to 0200 GMT.

and the locations of afternoon and early evening severe weather, as shown on the cover.

5. Summary

A method has been developed for displaying geostationary satellite sounding information in an image format. Clear air water vapor and stability are combined with cloud radiance to provide to a weather forecaster, in real time, a comprehensive image of the state of the atmosphere. A time sequence of these images allows the forecaster to monitor water vapor convergence and atmospheric stability changes usually antecedent to intense convective weather developments. At the same time the forecaster can monitor the cloud developments associated with these atmospheric water vapor and stability tendencies.

The utility of the sounding/cloud imagery product is currently being evaluated on a routine basis by forecasters at the National Severe Storms Forecast Center in Kansas City, Missouri. The initial response has been very favorable. As a result, this image product will most likely be available to all forecast centers beginning in 1986, when the VAS data acquisition and processing system becomes fully operational.

References


