COMPARISON OF CLOUD MOTION VECTOR HEIGHT ASSIGNMENT TECHNIQUES USING THE GOES-12 IMAGER

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ABSTRACT

Presently GOES cloud motion vector heights are assigned by any of three techniques when the appropriate spectral radiance measurements are available. In opaque clouds, infrared window (IRW) brightness temperatures are compared to forecast temperature profiles to infer the level of best agreement that is taken to be the level of the cloud. In semi-transparent clouds or sub-pixel clouds, since the observed radiance contains contributions from below the cloud, this IRW technique assigns the cloud too low a level. Corrections for the semi-transparency of the cloud are possible with the carbon dioxide (CO_2) slicing technique. This method uses radiances sensitive to different layers of the atmosphere, via a ratio technique, to infer the level of the cloud. A similar concept is used in the IRW-water vapor (H_2O) intercept technique. For this method H_2O radiances, influenced by upper tropospheric moisture, and IRW radiances exhibit a linear relationship as a function of cloud amount. This is used to extrapolate the correct height. The GOES-12 Imager measures IRW (10.7 μm), H_2O (6.5 μm), and CO_2 (13.3 μm) radiances and thus offers the opportunity to compare the three cloud motion height assignment techniques with data of the same target, same viewing geometry, and same time. Results using data from the GOES-12 post-launch science check-out are presented.

1. Technique Description

Semi-transparent or sub-pixel clouds are often the best tracers, because they show good radiance gradients that can readily be tracked and are likely to be passive tracers of the flow at a single level. Unfortunately their height assignments are especially difficult. Since the emissivity of the cloud is less than unity by an unknown and variable amount, its brightness temperature in the infrared window is an overestimate of its actual temperature. Thus, heights for thin clouds inferred directly from the observed brightness temperature and an available temperature profile are consistently low.

Presently heights are assigned by any of three techniques when the appropriate spectral radiance measurements are available (Nieman et al., 1993). In opaque clouds, infrared window (IRW) brightness temperatures are compared to forecast temperature profiles to infer the level of best agreement that is taken to be the level of the cloud. In semi-transparent clouds or sub-pixel clouds, since the observed radiance contains contributions from below the cloud, this IRW technique assigns the cloud to too low a level. Corrections for the semi-transparency of the cloud are possible with the carbon dioxide (CO_2) slicing technique (Menzel et al., 1983) where radiances from different layers of the atmosphere are ratioed to infer the correct height. A similar concept is used in the water vapor (H_2O) intercept technique (Szejwach, 1982), where the fact that radiances influenced by upper tropospheric moisture (H_2O) and IRW radiances exhibit a linear relationship as a function of cloud amount is used to extrapolate the correct height.

An IRW estimate of the cloud height is made by averaging the infrared window brightness temperatures of the coldest 25 percent of pixels and interpolating to a pressure from a forecast guess sounding (Merrill et al. 1991).

In the CO_2 slicing technique, a cloud height is assigned with the ratio of the deviations in observed radiances (which include clouds) from the corresponding clear air radiances for the infrared window and the CO_2 (13.3 μm) channel. The clear and cloudy radiance differences are determined from observations with GOES and radiative transfer calculations. Assuming the emissivities of the two channels are roughly the same, the ratio of the clear and cloudy radiance differences yields an expression by which the cloud top pressure of the cloud within the field of view (FOV) can be specified. The observed differences are compared to a series of radiative transfer calculations with possible cloud pressures, and the tracer is assigned the pressure that best satisfies the observations. The operational implementation is described in Merrill et al. (1991).

The H_2O intercept height assignment is predicated on the fact that the radiances for two spectral bands vary linearly with cloud amount. Thus a plot of H_2O (6.5 μm) radiances versus IRW (10.7 μm) radiances in a field of varying cloud amount will be nearly linear. These data are used in conjunction with forward calculations of radiance for both spectral channels for opaque clouds at different levels in a given atmosphere specified by a numerical weather prediction of temperature and humidity. The intersection of measured and calculated radiances will occur at clear sky radiances and cloud radiances. The cloud top temperature is extracted from the cloud radiance intersection (Schmetz et al., 1993).

2. Results of Comparison

a. All clouds

Comparison of these height assignment techniques was accomplished with data from the GOES-12 on 25 September 2001. The multispectral imager from GOES-12 measures IRW (centered at 10.7 μm) and H_2O (centered at 6.5 μm) radiances from 4 km FOVs and CO_2 (centered at 13.3 μm) radiances from 8 km FOVs. Cloud elements were selected by the autowindco procedure (Merrill et al., 1991) that divides the entire image into cells (roughly 60 km on a side) and selects targets based on the overall brightness and contrast of the scene. Height assignments were made with all three methods described in the previous section. Table 1 presents the results corresponding to 3653 targets. Mean cloud top pressures for all the height assignments using a single technique are calculated and the root mean square (rms) scatter about that mean is also calculated; the scatter is due to natural variability in the cloud heights as well as technique inaccuracy. The rms deviation of heights for all the tracers using one technique with respect to those using another technique are also presented; this value represents the deviation of one technique with respect to the other.

Table 1: IRW, CO_2/IRW, and H_2O/IRW height assignments for cloud tracers using GOES-12 radiances from 25 September 2001.

	Mean Cloud Top	RMS wrt	RMS Deviation (hPa)	
(3653 tracers)	Pressure (hPa)	Mean (hPa)	wrt CO_2/IRW	wrt H_2O/IRW
IRW	515	101	142	196
CO_2/IRW	367	59	--	130
H_2O/IRW	286	60	130	--

The H_2O height assignments are on the average 80 hPa higher in the atmosphere than the CO_2 height assignments. The IRW heights, without benefit of any semi-transparency correction, are about 150 hPa lower in the atmosphere than the CO_2 height assignment on the average. Figure 1 shows the histogram plots; the H_2O/IRW and CO_2/IRW cloud top pressures show reasonable agreement. Height assignments show more disagreement low in the atmosphere than high as both techniques show more skill higher in the troposphere. IRW versus H_2O/IRW and CO_2/IRW estimates show larger disagreement; many of the IRW cloud top pressures are unrealistically low in the atmosphere, due to the semi-transparency of the high cloud tracers selected.

When the three techniques are compared as a function of the effective cloud amount (see Figure 2), the comparison improves with increasing effective cloud amount. This is understandable as there is less correction for semi-transparency as the clouds become more opaque.

For all of the cloud tracers selected for vector calculation in the scene on 25 September 2001, the CO_2 slicing algorithm failed to produce a height for about 5% of the tracers and the H_2O intercept failed for about 25% of the tracers. This is in part due to the instability of the H_2O/IRW cluster extrapolation to cloud top pressure. The CO_2 technique is more robust and provides a CTP assignment more often.

b. Cirrus

A comparison was isolated to cirrus clouds only with GOES-12 imager data from 27 October 2001. Figure 3 shows the selected scene. Table 2 shows the results. The H_2O height assignment is now on the average 80 hPa lower in the atmosphere than the CO_2 height assignment (in contrast to the all clouds comparison where H_2O assignments are 80 hPa higher in the atmosphere). Absorption in ice is greater at CO_2 wavelengths (13.3 µm) than at H_2O wavelengths (6.5 µm), so the H_2O intercept technique is not as sensitive to ice and hence will see deeper into the cirrus before it responds. The CO_2 slicing demonstrates less rms scatter (47 hPa) than the H_2O intercept (69 hPa). The IRW heights, without benefit of any semi-transparency correction are about 350 hPa lower in the atmosphere than the CO_2 height assignment on the average and have a large rms scatter (122 hPa).

For the cloud tracers in the scene on 27 October 2001, the CO_2 slicing algorithm produced a height assignment for all of the tracers while the H_2O intercept failed for about 50% of the tracers. The CO_2 technique is much more robust in thin cirrus.

Table 2: IRW, CO_2/IRW, and H_2O/IRW height assignments for thin cirrus tracers using GOES-12 radiances from 27 October 2001.

(213 tracers)	Mean Cloud Top Pressure (hPa)	Scatter wrt Mean (hPa)	RMS Deviation (hPa) wrt CO_2/IRW	wrt H_2O/IRW
IRW	565	122	118	139
CO_2/IRW	212	47	--	72
H_2O/IRW	288	69	72	--

3. Conclusions

The GOES-12 results presented in this paper suggest that the H_2O/IRW intercept technique and the CO_2 slicing technique for inferring the heights of semi-transparent cloud elements produce similar results. The heights from the two approaches compare to within 80 hPa. The effectiveness of the H_2O/IRW intercept technique tends to be reduced for thin cirrus tracers. CO_2 slicing is more robust (has fewer failures in producing cloud top pressure for a set of cloud tracers). The infrared window channel technique consistently places the semi-transparent cloud elements too low in the atmosphere by 100 hPa or more; only in more opaque clouds does it perform adequately.

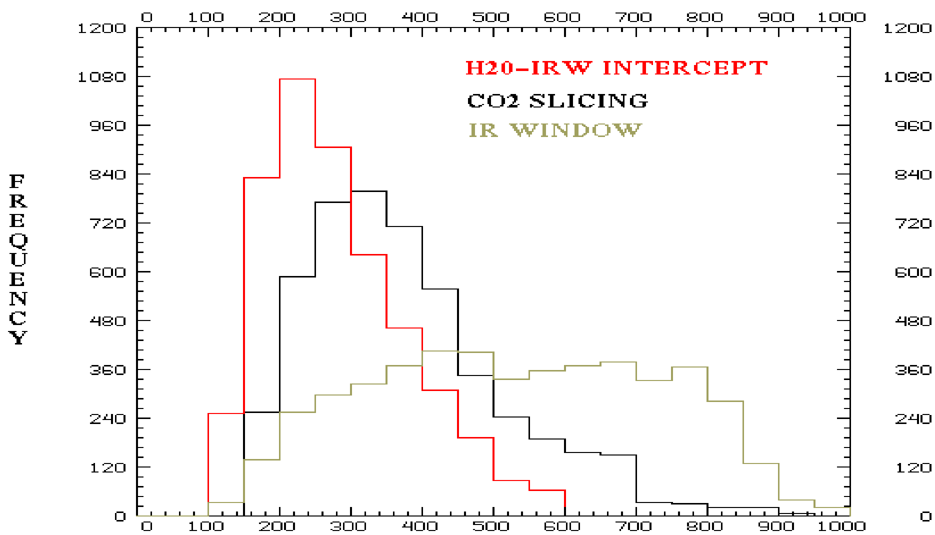

Figure 1. Histogram plots of H_2O/IRW, CO_2/IRW, and IRW cloud top pressures for 3653 cloud targets on 25 September 2001.

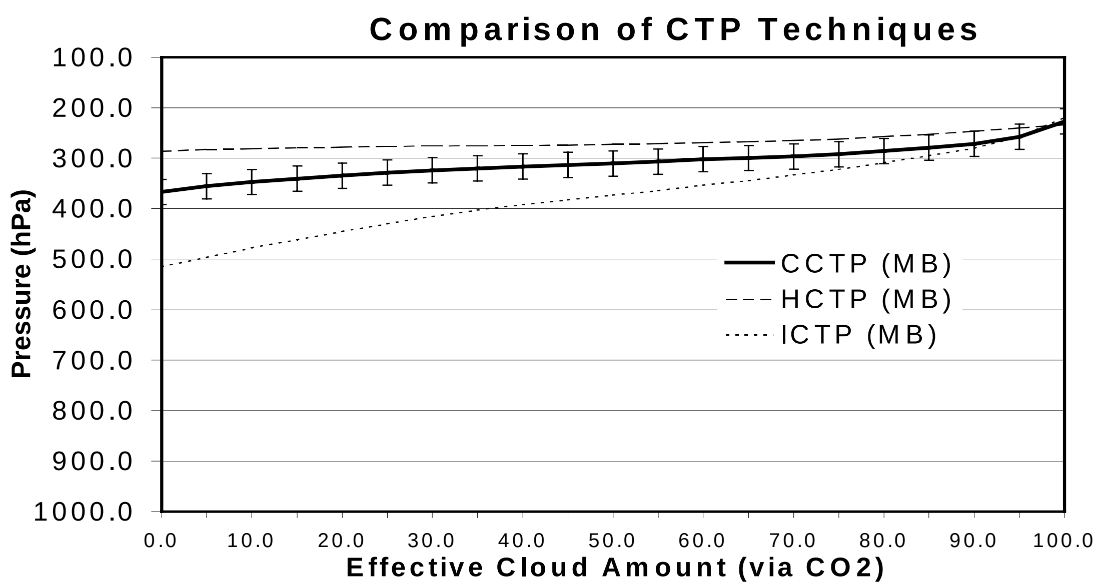

Figure 2. Comparison of the cloud top pressures estimated by the H_2O/IRW, CO_2/IRW, and IRW as a function of the effective cloud amount (estimated from the CO_2 slicing technique).

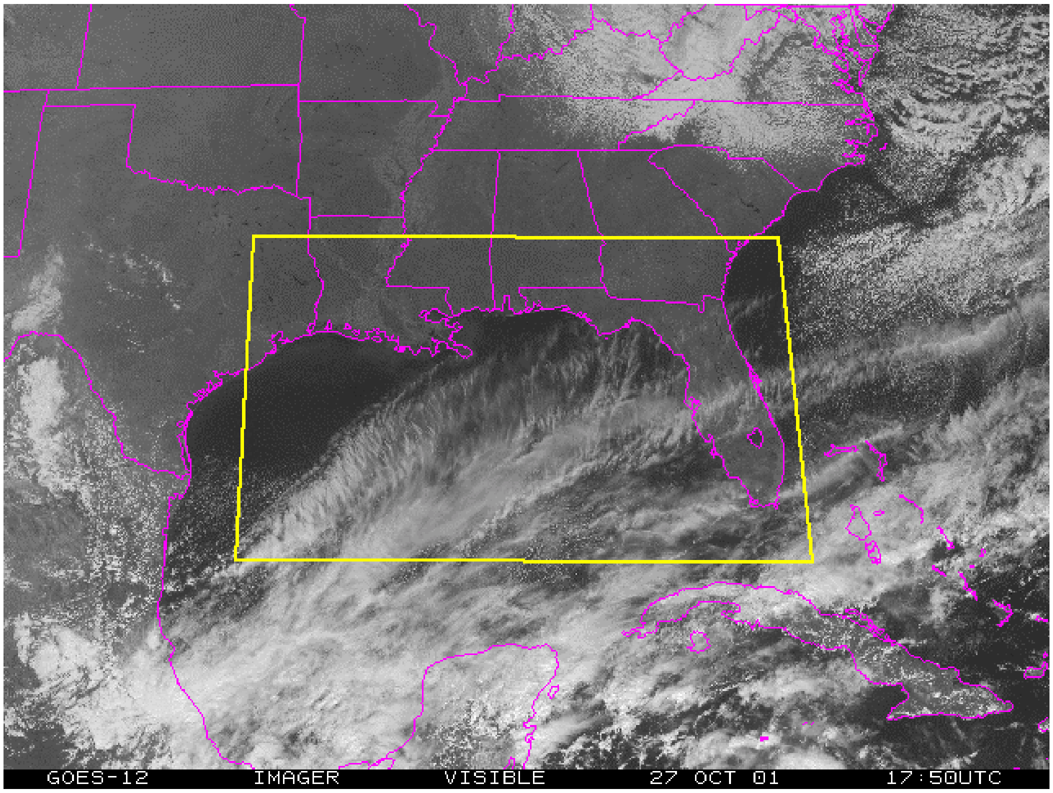

Figure 3. Visible image of cirrus clouds selected for cloud top pressure intercomparison in GOES-12 measurements from 27 October 2001.

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