CGMS XXIX
USA-WP-33
AGENDA ITEM: III/4
DISCUSSED IN WG III

CLOUD MOTION VECTOR HEIGHT ASSIGNMENT TECHNIQUES

PURPOSE AND SUMMARY OF DOCUMENT

This paper presents an overview of the procedures for cloud motion vector height assignment techniques and the results of some intercomparisons.

CLOUD MOTION VECTOR HEIGHT ASSIGNMENT TECHNIQUES

W. Paul Menzel
NOAA/NESDIS/ORA, Madison, Wisconsin

1. Summary of Techniques

Semi-transparent or sub-pixel clouds are often the best tracers, because they show good radiance gradients that can readily be tracked and they 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 which 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 (CO2) 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 (H2O) intercept technique (Szejwach, 1982), where the fact that radiances influenced by upper tropospheric moisture (H2O) 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 CO2 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 CO2 (13.3 micron) 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 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 H2O intercept height assignment is predicated on the fact that the radiances for two spectral bands vary linearly with cloud amount. Thus a plot of H2O (6.5 micron) radiances versus IRW (11.0 micron) 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).

Satellite stereo height estimation has been used to validate H2O intercept height assignments. The technique is based upon finding the same cloud patch in several images. For cloud motion, the cloud needs to change slowly relative to the image frequency. For stereo heights, the cloud needs to be distinct and appear nearly the same from the two viewpoints (after re-mapping to the same projection). Campbell (1998) built upon earlier work of Fujita and others (Fujita, 1982) to develop a method which adjusts for the motion of the cloud so that simultaneity is not required for the stereo height estimate. A test analysis was performed with Meteosat – 5 / 7 data; stereo heights and H2O intercept heights agreed within 50 hPa. As more geostationary and polar orbiting satellites remain in operation, the prospects for geometric stereo height validations of the operational IRW, H2O intercept, and CO2 slicing heights become very promising.

2. Summary of Intercomparisons

Initial comparison of these three height assignment techniques was accomplished with data from the Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS) in January 1992 and reported in Nieman et al. (1993). The multispectral imaging from VAS measures IRW (10.4 to 12.1 microns) radiances from 8 km FOVs and H2O (6.4 to 7.1 microns) and CO2 (13.2 to 13.5 microns) radiances from 16 km FOVs. Cloud elements were selected by the autowindco procedure (Merrill et al., 1991) which divides the entire image into cells (roughly 100 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 200 targets in mid-latitudes (20 to 50N latitude, 50 to 100W longitude) for 29, 30, and 31 January 1992. 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 for these days 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.

The H2O height assignment is on the average 30 hPa higher in the atmosphere than the CO2 height assignment. The IRW heights, without benefit of any semi-transparency correction are about 70 hPa lower in the atmosphere than the CO2 height assignment on the average. Figure 3 shows the scatter plots for these three days. The H2O/IRW and CO2/IRW cloud top pressures in Figure 3A fall close to the line of one-to-one correspondence; agreement is within 50 hPa rms for the top of the troposphere and drops off to 100 hPa rms near 600 hPa. Both techniques show more skill higher in the troposphere. Some of the IRW cloud top pressures are unrealistically low in the atmosphere, due to the semi-transparency of the high cloud tracers selected. IRW versus H2O/IRW and CO2/IRW estimates show larger disagreement near the top of the troposphere (about 150 hPa rms) than at 600 hPa (about 100 hPa rms).

On 29 January the H2O/IRW intercept and the CO2/IRW ratio yield similar mean cloud top pressures (304 and 314 hPa respectively) and the scatter (60 and 59 hPa respectively) in the heights of the clouds observed with respect to the average height is almost the same. The statistical properties for both methods are the same. The rms deviation between the two methods is 66 hPa, indicating very good agreement. The IRW heights were much lower on the average (390 hPa) and showed more scatter (101 hPa); the absence of any semi-transparency correction is the probable cause.

On 30 January, the H2O/IRW intercept produced cloud top pressures 54 hPa higher in the atmosphere than the CO2/IRW ratio. The scatter of the H2O/IRW results is only 51 hPa as opposed to the 81 hPa of the CO2/IRW results. The rms deviation between the methods is 82 hPa. Explanation of these somewhat degraded results one day later may rest in the fact that the upper troposphere was drier on the 30 January than on the previous day; this is noticeable by the increase in mean water vapor channel brightness temperature over the cloud tracers from 232 K on 29 January to 235 K on 30 January. In a drier atmosphere, clouds will exhibit lower emissivity in the infrared window and so the IRW channel measures warmer radiances; however the water vapor attenuation in the H2O channel remains disproportionately high (the H2O channel is sensitive to only the first few tenths of a millimeter of water vapor). This combination of less sensitive IRW and more sensitive H2O will produce large slopes between cloudy and clear sky clusters and yield H2O/IRW intercept estimates that are too high in the atmosphere (Schmetz et al., 1993). The IRW technique again places the clouds much lower than either of the other two techniques and scatters them about more.

On 31 January, the H2O/IRW intercept produced cloud top pressures 41 hPa higher in the atmosphere than the CO2/IRW ratio. The scatter of the H2O/IRW results is only 78 hPa as opposed to the 107 hPa of the CO2/IRW results. Root mean square deviation between the methods is 107 hPa. Again drier conditions prevailed (the mean water vapor channel brightness temperature over the cloud tracers has now risen to 237 K on 31 January) and it is suspected that the H2O/IRW intercept is suppressing some of the actual variation in the cloud top pressures.

Table 1. IRW, CO2/IRW, and H2O/IRW height assignments for cloud tracers using VAS radiances from 20 to 50N and 50 to 100W for 29-31 January 1992.

29 Jan 1992	Mean Cloud Top	Scatter wrt	RMS Deviation (hPa)	
(87 tracers)	Pressure (hPa)	Mean (hPa)	wrt CO2/IRW	wrt H2O/IRW
IRW	390	101	123	133
CO2/IRW	314	59	--	66
H2O/IRW	304	60	66	--

30 Jan 1992	Mean Cloud Top	Scatter wrt	RMS Deviation (hPa)	
(51 tracers)	Pressure (hPa)	Mean (hPa)	wrt CO2/IRW	wrt H2O/IRW
IRW	434	93	82	137
CO2/IRW	378	81	--	82
H2O/IRW	324	51	82	--

31 Jan 1992	Mean Cloud Top	Scatter wrt	RMS Deviation (hPa)	
(61 tracers)	Pressure (hPa)	Mean (hPa)	wrt CO2/IRW	wrt H2O/IRW
IRW	438	103	107	156
CO2/IRW	360	107	--	107
H2O/IRW	319	78	107	--

All 3 days	Mean Cloud Top	Scatter wrt	RMS Deviation (hPa)	
(199 tracers)	Pressure (hPa)	Mean (hPa)	wrt CO2/IRW	wrt H2O/IRW
IRW	416	102	109	141
CO2/IRW	344	87	--	85
H2O/IRW	314	65	85	--

References

Campbell, G. G., 1998: Applications of synchronous stereo height and motion analysis. Proceedings of the fourth International Winds Workshop, EUMETSAT publication **24**, 271-278.

Fujita, T., 1982: Infrared, stereo, cloud motion, and radar-echo analysis of SESAME-day thunderstorms. 12th Conf. on Severe Local Storms, Jan 11-15, San Antonio, TX, Amer. Meteor. Soc., Boston, MA, 213-216.

Menzel, W. P., W. L. Smith, and T. R. Stewart, 1983: Improved cloud motion wind vector and altitude assignment using VAS. *J. Clim. Appl. Meteor*., **22**, 377-384.

Merrill, R. T., W. P. Menzel, W. Baker, J. Lynch, and E. Legg, 1991: A report on the recent demonstration of NOAA's upgraded capability to derive cloud motion satellite winds. *Bull. Amer. Meteor. Soc.*, **72**, 372-376.

Nieman, S. J., J. Schmetz and W. P. Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers. *J. Appl. Meteor*., **32**, 1559-1568.

Nieman, S. J., W. P. Menzel, C. M. Hayden, D. Gray, S. T. Wanzong, C. S. Velden, and J. Daniels, 1997: Fully automated cloud drift winds in NESDIS operations. *Bull. Amer. Meteor. Soc*., **78**, 1121-1133.

Schmetz, J., K. Holmlund, J. Hoffman, B. Strauss, B. Mason, V. Gaertner, A. Koch, and L. van de Berg, 1993: Operational cloud motion winds from METEOSAT infrared images. *J. Appl. Meteor*., **32**, 1206-1225.

Szejwach, G., 1982: Determination of semi-transparent cirrus cloud temperatures from infrared radiances: application to Meteosat. *J. Appl. Meteor*., **21**, 384.