Cloud Motion and Height Measurements from Multiple Satellites Including Cloud Heights and Motions in Polar Regions

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ABSTRACT

This paper describes work underway at CIRA that is focused on deriving extremely accurate cloud motions (0.5 m/s) and heights (500 m) using geostationary satellite imagery. Emphasized are the use of cloud relative animation to assure target selection and shadows for cloud height determination. Advanced techniques that rely on time adjusted stereo with geostationary imagery, and the combination of height adjusted stereo and shadows for cloud heights and velocities from polar orbiting satellites are introduced.

1. INTRODUCTION

As pointed out in the February 20-21, 1992 **Workshop on Cloud Motion Winds,** the need exists to improve the accuracy and number of cloud motion winds, globally in coverage and eventually mesoscale in resolution. Large errors in cloud drift wind velocity and height assignment from geostationary satellites have been noted by operational forecast centers, notably NMC and ECMWF. Among the major culprits, the inability to derive good winds in complex situations, such as routinely exist in jet stream regions, and poor height assignment for clouds that are used as tracers. In addition, geostationary coverage in polar regions is not possible, and no method for obtaining accurate cloud motions and heights from pairs of polar satellite images has been demonstrated. Work is underway at CIRA to remedy those problems.

2. COMMENTS REGARDING CLOUD HEIGHT ASSIGNMENT 2.1

Infrared based techniques

From satellites, both high resolution visible and infrared imagery are used for the tracking of clouds, while infrared imagery is used for cloud height assignment. Two major problems encountered when using infrared imagery for cloud height assignment are: 1) cloud emissivity; and, 2) knowledge of the lapse rate to which the cloud's temperature will be matched. Recently, a technique known as C02 slicing (Menzel) that uses multi-spectral aspects of GOES-VAS has been developed to aid in cloud height assignment. That technique eliminates some of the uncertainties due to cirrus emissivity, however, the problem of a representative lapse rate in the vicinity of the cloud remains. In addition, C02 slicing will not be possible with the GOES-I/M series of spacecraft since one of the needed channels is not included on those spacecraft's imagers. Instead, a technique that is not as accurate as C02 slicing will be employed: water vapor slicing. For NOAA polar orbiting satellites, neither the water vapor or C02 channels are available.

2.2 Geometric techniques

Since geometry does not rely on cloud properties, that methodology may be preferable for use in deriving cloud heights. Recognizing the problem encountered using infrared imagery for cloud height assignment, stereographic techniques (Hasler) were developed to very accurately determine cloud heights using imagery from two geostationary satellites (Figure 1).

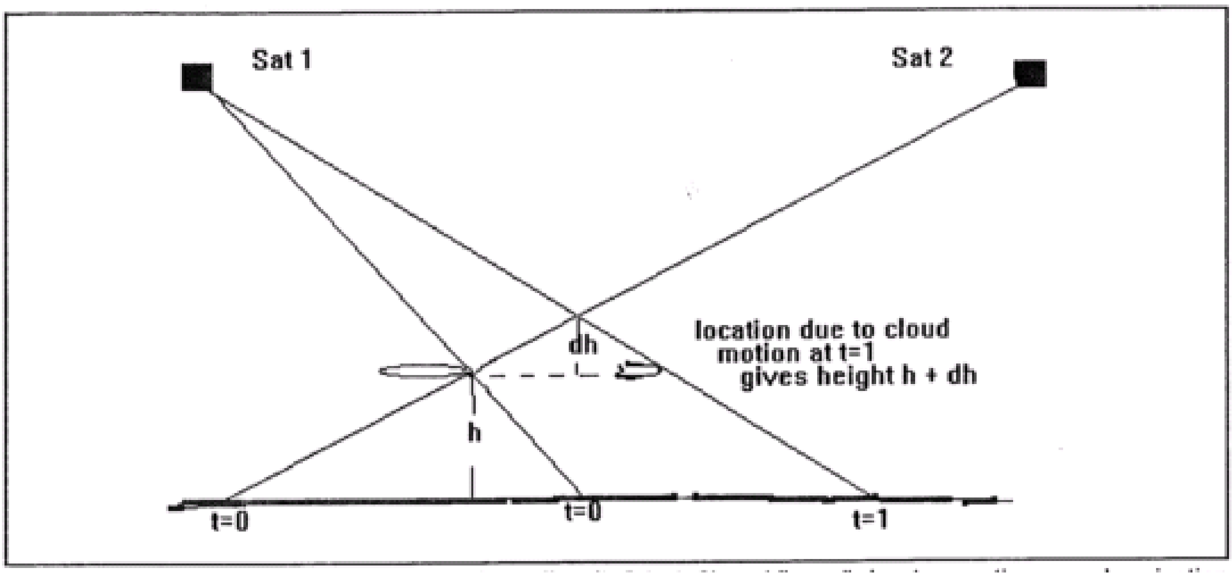

Figure 1. Stereo geometry showing base-line (t=0 to t=0) and "error" due to non-time synchronization (cloud motion).

While stereo techniques provided accurate cloud height assignment (depending on satellite separation distance), some limitations were thought to exist at the time of Hasler's work:

1) a requirement for the geostationary satellites to scan in a synchronous fashion or height errors would be introduced due to cloud motion; and,

2) stereo was only done using visible imagery.

Today, stereo is not done operationally for a number of reasons:

1) the perceived need for time synchronization between satellites;
2) the desire for automated techniques (at the expense of accuracy?); and,
3) the idea that stereo is a visible only technique.

A geometrically based technique that overcomes the requirement for two satellites was developed at CIRA by Dills: the calculation of cloud height using shadows. That technique is limited to daytime and performs best early or late in the day when shadows are distinct and long (Figure 2).

3. COMMENTS REGARDING CLOUD VELOCITY

While the problems related to cloud height assignment are rather straight forward and easy to conceptualize, the same cannot be said for cloud velocity. We believe the major questions that needs to

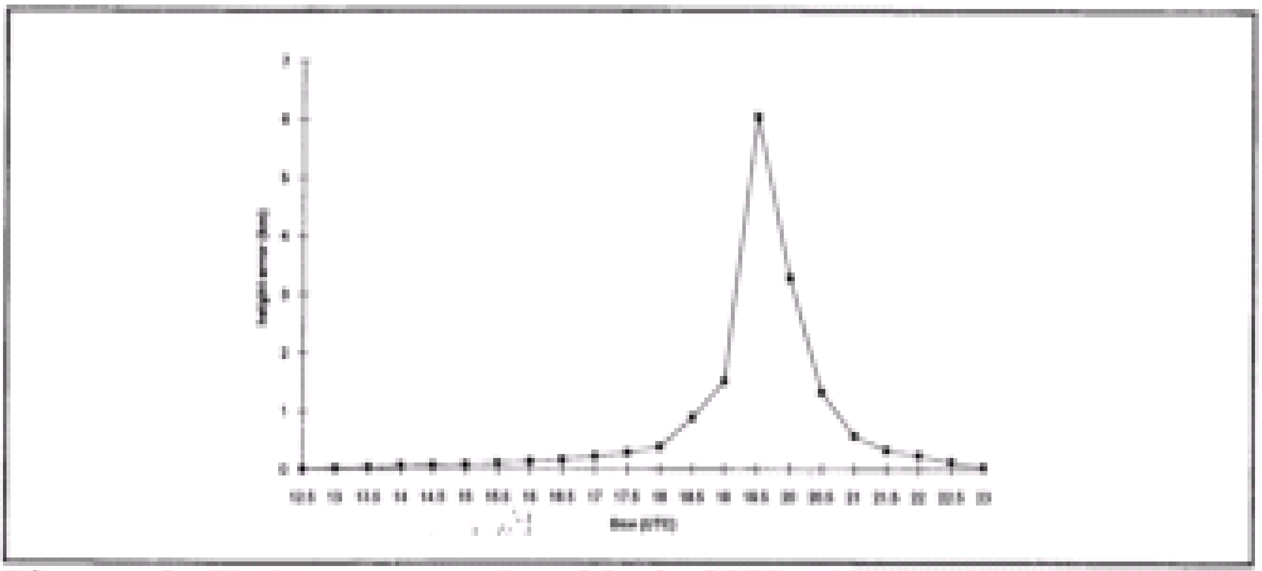

Figure 2. Shadow accuracy vs time of day for GOES at 112W (at Chicago on 10/15/93)

be addressed concerning cloud velocity versus wind are two-fold. First is target identification and continuity; second is correct verification of a cloud velocity versus the real wind.

3.1 Target identification and continuity

Target identification and continuity are largely a matter of image frequency and wind derivation technique. A number of studies have shown that more frequent imagery improves an operators ability to detect cloud targets; however, most operational systems still use only on 30 minute interval imagery. Since most wind derivation techniques are automated and use 30-minute interval imagery, they have great difficulty with cloud target identification in complex, multilayered cloud situations. Thus, around baroclinic zones and in tropical convective regimes where accurate cloud drift winds are highly desirable, those winds are not available. Using "cloud relative animation" to help ensure target identification and continuity, researchers at CIRA have had great success in deriving very accurate cloud motions in complex situations (even with 30 minute interval imagery when the tracer is cirrus); however, in its current form this is a manual system.

3.2 Accuracy of cloud drift winds

There have been a variety of studies undertaken to determine the accuracy of cloud drift winds. "Errors" have been reported that are extremely large in certain cases, and as low as a few meters per second in others. While certain of the errors may have been due to operator error (in which we include navigation and other spacecraft/ground equipment factors), we believe a major factor is improper verification technique (which includes height assignment). Specifically, not using a measured wind that exactly matches in time and location the cloud drift wind's time and location. Especially abhorrent are studies that have used rawinsondes whose temporal and spatial separation from the cloud drift wind ignore the mesoscale characteristics of the atmosphere, especially in more dynamic situations.

4. WORK UNDERWAY AT CIRA

Significant strides have been made at CIRA in the area of deriving cloud motions and their heights using geostationary satellite imagery. Those efforts have concentrated in the area of deriving fine scale detail from the cloud motion field using manual techniques. Accomplishments include: 1) development of a cloud relative animation technique that aids in the unambiguous selection of targets; 2) development of a cloud height measurement technique that utilized cloud shadows and parallax adjustments; and, 3) detailed verification of CIRA derived cloud drift winds. Using a specialized "cloud relative motion" manual tracking technique for target recognition and velocity determination, and shadows for determination of cloud height, Dills and Smith compared velocities of satellite observed cirrus cloud with those from ground based wind profilers. They found that the velocities matched to within the measurement errors inherent to the two

Systems. CIRA's expertise in deriving very accurate cloud drift winds was recently verified in a comparison with ground based stereo (Fujita, to be presented elsewhere at this workshop): CIRA's cloud velocities and heights were found to be **a near perfect match.**

4.1 Time adjusted stereo

The objective of our recent work has been to develop an improved method for making the best possible measurements of cloud height. The method focuses on stereographic techniques, but does not require time synchronization between the two satellite's images used to make the height determination. The technique, "time adjusted stereo," uses the cloud motion determined from one satellite to adjust the location of the cloud with respect to the observation time of the other satellite. This technique has the advantage of allowing a mix of satellite types, so that higher resolution AVHRR multi-channel imagery may be combined with that from geostationary satellite imagery.

Time adjusted stereo requires very accurate cloud motions (to within a few meters per second depending on cloud speed). For two geostationary satellites operating in a nominal 30 minute interval mode, the maximum time separation between views of the same cloud by the two satellites is 15 minutes: a cloud moving 60 m/s will have moved 54 km during that time. For GOES satellites at 75 and 135 West, the apparent difference in earth location for a 10 km high cloud over Chicago (stereo base-line) is about 28 km. A 3 km error in base-line measurement for stereo would translate to a 1.1 km error in height (for a 10 km high cloud). Thus, for the case mentioned above, if base-line measurement errors are solely due to cloud motion, a precision of 1 meter per second will keep height errors less than 350 meters. For a cloud over Acapulco, Mexico, similar calculations yield a 15 km base-line, with 3 km measurement error causing a 2 km height error for a 10 km high cloud, while a 1 m/s velocity error (for a 60 m/s cloud) translates to a 600 meter height error. It must be stressed here, that the ability to very accurately define cloud height with time adjusted stereo does not depend on how well a cloud's motion matches that of the real wind, but rather how precisely the cloud's motion can be measured.

4.2 Possibility for accurate polar winds

Recently, we have come to realize that a combination of stereo and shadow techniques makes it possible to get very accurate cloud velocities and heights from pairs of AVHRR images at high latitudes, obviously during daylight. As with the time adjusted stereo technique mentioned above, the problem becomes one of solving for one of the two unknowns, a cloud's height or velocity, which then allows the determination of the other. With daytime AVHRR visible imagery at high latitudes, very good shadows may be used to determine cloud height. The question then becomes one of target identification, remapping and base-line for stereo. With the unadjusted stereo, trie cloud height will have a bias because of motion; however, when shadows are used to determine height precisely, only the velocity bias is left.

5.0 CONCLUSIONS

Work underway, or planned, at CIRA holds the promise of allowing very accurate cloud heights and velocities to be derived from pairs of satellite imagery. The techniques (shadows, cloud relative motion, time adjusted stereo) are manual and are only available for research applications at this time. When these techniques have been used (shadows and relative motion) with geostationary imagery, extreme precision has been demonstrated. CIRA plans to undertake the following activities as resources permit:

1) develop algorithms for cloud height measurement from shadows for polar orbiting imagery;
2) modify existing geostationary stereo techniques for velocity input - time adjusted stereo;
3) develop multi-satellite (polar/geostationary and polar/polar) stereo algorithms;
4) combine 1), 2) and 3) above to derive accurate polar winds during daytime;
5) develop interactive computer techniques to relieve part of the (manual) burden in deriving accurate cloud drift winds and their heights without sacrificing accuracy.