Detailed Cloud Motions from Satellite Imagery
Taken at
Thirty Second
One and Three Minute Intervals

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ABSTRACT

Since the launch of GOES-8, a number of special imaging sequences have been performed where high resolution imagery has been acquired over the same scene at thirty second, one and three minute intervals. Sequences include eye catching phenomena like severe thunderstorms and hurricanes, as well as more common situations like winter storms with multiple layers of clouds and trade wind flow over ocean areas. Research is showing that imagery at such high frequencies are very good for deriving mesoscale cloud motions, even in the most complex of situations. Results point toward cloud drift wind improvements in the future based on geostationary satellites being operated in "special adaptive observing scenarios" to provide dense and highly accurate wind fields in regions of importance, including regions of anticipated model impact.

1. INTRODUCTION

It is well known that the need exists to improve the accuracy and number of cloud motion winds, globally in coverage and eventually mesoscale in resolution. Meeting this accuracy challenge requires overcoming a number of problems. Among the major problems: 1) faulty target selection which leads to poor quality winds in complex situations as well as the inability to track low clouds over land because of their life time; and, 2) poor height assignment for clouds that are used as tracers. This paper is one of two papers at this workshop describing work underway at CIRA to help remedy those problems. In this paper, which basically addresses target selection, it will be shown that very accurate mesoscale cloud drift wind fields can be determined using geostationary satellite imagery taken at very frequent intervals. The other paper, by Campbell et al (1996) addresses the cloud height issse.

The new generation of GOES satellites (GOES-8 being the first of the series) can take imagery at intervals as frequent as once every 30 seconds. This capability has provided the opportunity to observe cloud motions and development from space with a frequency here to fore not realized.

These data are showing that the limiting factor for cloud motion determination is, as one might expect, cloud life time. Those data are also showing that highly detailed cloud motions may be derived over mesoscale areas.

2. TARGET IDENTIFICATION AND CONTINUITY

With the new GOES system, which is a body stabilized spacecraft, images with different time bases may be mixed, so that sequential observation times at the clouds in different portions of the image can be different by several minutes. This is because of the different operational scan modes used with GOES (Menzel and Purdom, 1994). Thus, with the new GOES, time must be tracked on a line by line basis, image to image, when frequent interval imagery is mixed with operational imagery and used for cloud tracking.

Target identification is largely a matter of image frequency (cloud lifetime) 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, such winds are not available. In addition, over land, where low level cloud lifetimes are on the order of minutes, it is virtually impossible to identify the same cumulus cloud on images 15 minutes apart, much less at 30 minute intervals.

Investigations at CIRA have shown, for manual cloud tracking, that use of "cloud relative animation" helps ensure target identification, especially at image frequencies greater than 5 minutes. Cloud relative animation requires an operator to identify a particular cloud within a sequence of images. After identifying the cloud using the cursor and computer mouse, the image sequence is reloaded (based on a storm relative motion algorithm) so that the cloud in question remains stationary during animation (land now moves), while similar clouds move very little. This allows the operator to study the cloud (and cloud field) and identify which portion of the cloud represents the best possible target. Scientists at CIRA have had great success in deriving very accurate cloud motions in complex situations using this technique; indeed, storm relative animation at CIRA was used to provide Fujita (1993) with the exceptionally accurate cloud motion vectors used in Figure 7 at the last International Winds Conference.

Cloud motion from imagery at one minute intervals is revealing differences in cloud motions within cirrus cloud targets. While these differences are generally small, we should be aware that they exist. For example in the companion paper by Campbell et al (1996), the clouds in Figure 6 were followed in great detail using one minute interval imagery. Within the cirrus region, areas that appear to be virga streamers are evident. Those streamers move with slightly different velocities than the cloudiness in the main cirrus area. When such small deviations can be seen in the cloud fields from a satellite perspective, and have been noticed from the ground for years, one must once again question studies that have used rawinsondes whose temporal and spatial separation from the cloud drift wind ignore the mesoscale characteristics of the atmosphere.

When very rapid interval imagery is used for cloud motion determination, other factors such as registration and amount of time a cloud spends within a pixel must be taken into consideration (these are also addressed by Campbell et al (1996)). Basically for manual cloud tracking, we have found that the most important use of very frequent interval imagery is in assuring target identification - we always try and maximize the time interval used for the vector measurement.

3. SOME SPECIFIC EXAMPLES

The cloud motions shown in the examples below were derived using cloud relative motion. Image frequencies varied from one to three minutes, except in the final example where image sequences of 30, 15, 5, 1 minute and 30 seconds were derived from the same cloud field for comparison purposes. Cloud heights were only identified as high or low, depending on type.

3.1 Three minute interval imagery.

During November, 1995, the GOES-9 satellite was placed in a special (near continuous) three minute interval imaging mode over the United States. The example shown in Figure 3.1 a and 3.l b is of an image from that period (3.1 a) along with low level cloud drift winds (3.1 b) derived from a sequence of those images. It was not possible to derive a meaningful wind field from imagery at longer time intervals (6, 9, 15 minutes, etc) because of the short lifetime of the cold air cumulus over the lakes. In the imagery and associated wind fields, notice the vortex and shear line over Lake Superior (Northwest lake), the easterly flow and resulting convergence zone across northern Lake Michigan (south of Lake Superior), and the strong northeasterly flow across Lake Huron (eastern most winds). This detailed flow was not detectable from conventional observations, and the location of the shear line over Lake Superior (along with evidence of vortex sheet breakdown) as well as the convergence line over northern Lake Michigan were not located in conventional meteorological data.

Figure 3.1a. High resolution GOES-9 visible imagery taken from a sequence of three minute images over the Great Lakes of the United States on November 13, 1995.

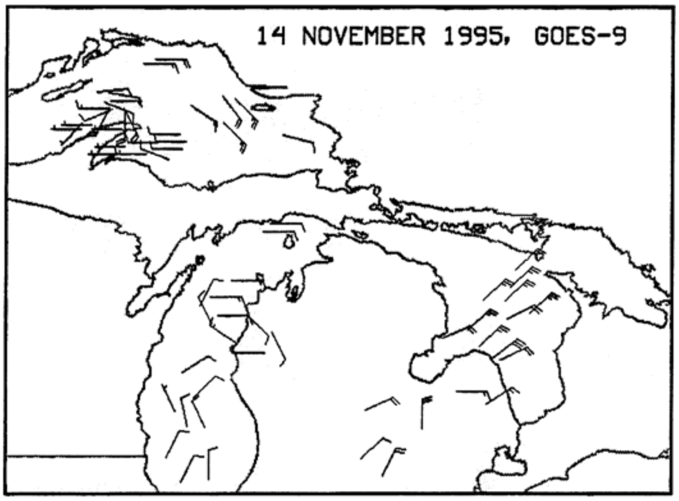

Figure 3.1 b. Detailed wind field derived from three minute satellite imagery from data over the area shown in Figure 3.1a.

3.2 One minute interval imagery over hurricanes

During the 1995 Atlantic hurricane season, bursts of one minute interval imagery were taken of every major hurricane that approached the coast of the United States. In addition, with GOES-8 at 75 West and GOES-9 at 90 West, a limited set of one minute interval stereo images were taken. As with three minute interval imaging in the previous example, one minute interval imagery of hurricanes revealed great detail in the cloud motion field. Basically, any cloud that could be detected could be tracked. Examples are shown in Figures 3.2a,b,c and d.

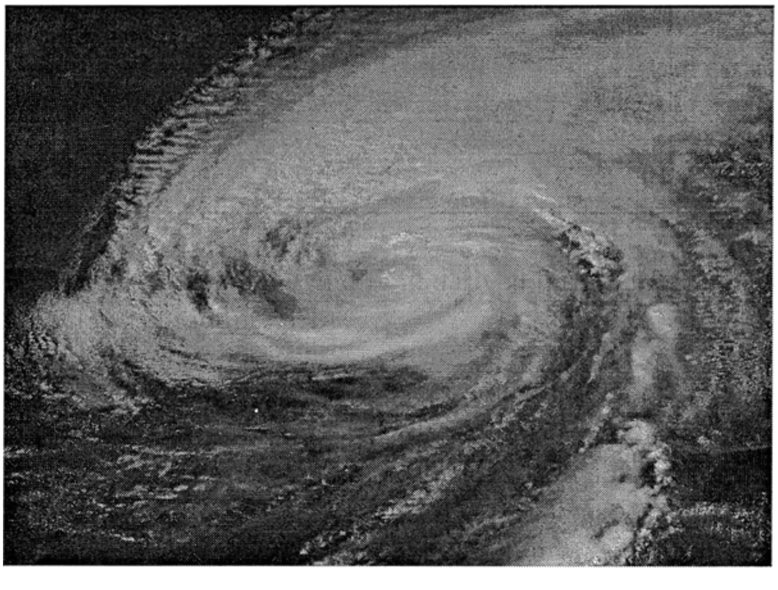

Figure 3.2a. High resolution visible image from a series of one minute interval images of hurricane Opal on October 4, 1995.

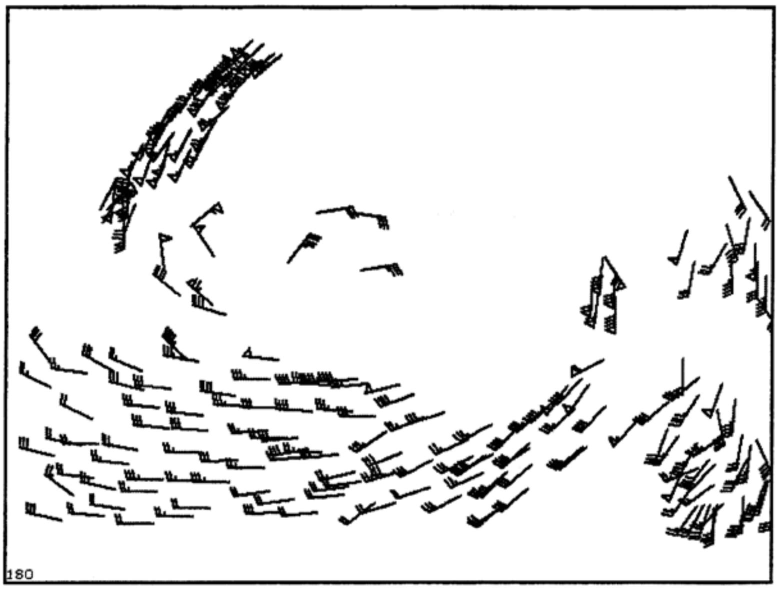

Figure 3.2b. Portions of detailed cumulus and cirrus level winds from hurricane Opal, Figure 3.2a. Notice the strong winds in the cirrus level outflow channel (upper left). Also notice how some low level winds were detectable beneath thin portions of the cirrus shield.

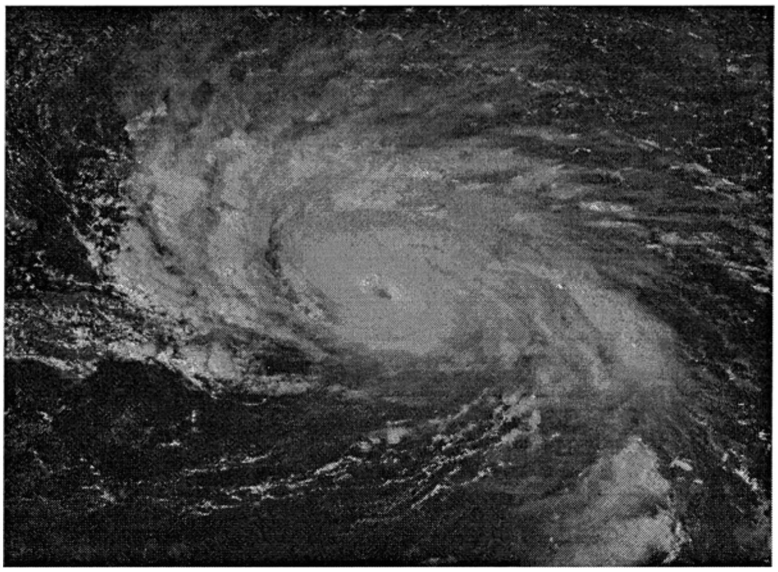

Figure 3.2c. High resolution visible image from a series of one minute interval images of hurricane Marilyn on September 16, 1995.

Other interesting features have been tracked using one minute interval imagery around hurricanes. Still under investigation are winds from within the eye wall of hurricane Luis. Those winds show evidence of a secondary vortex within the eye; apparently confirmed by research aircraft flights.

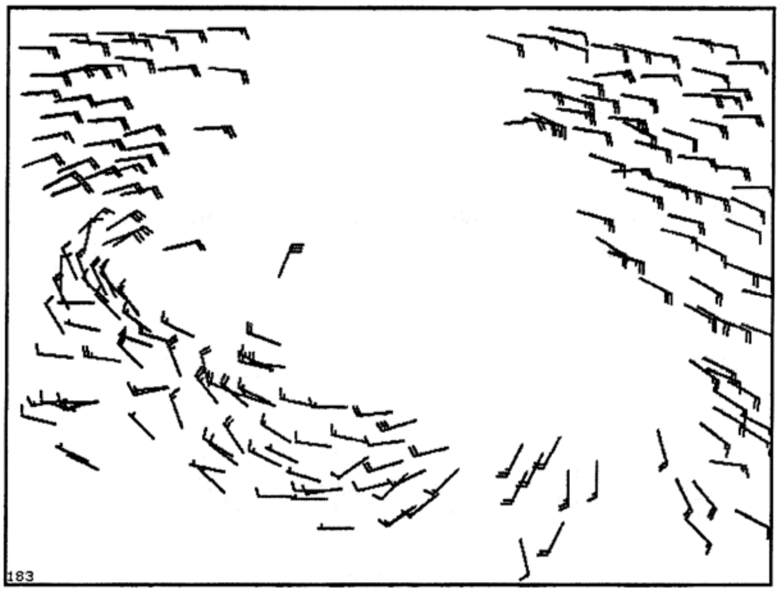

Figure 3.2d. Portions of detailed cumulus winds from hurricane Marilyn, Figure 3.2c. Notice how well the cumulus winds define the low level flow around the storm.

3.3 30 second interval imagery around severe thunderstorms

During the 1996 severe storm season selected cases have occurred where 30 second interval imagery was interspersed within the normal GOES-8 imaging sequence. In this special research/operational mode, fifteen 30 second images were interleaved between 5 to 15 minute imagery. The examples that follow are from April 12, 1996, a case where severe thunderstorms developed over Texas. The image shown in Figure 3.3a is from the 30 second sequence.

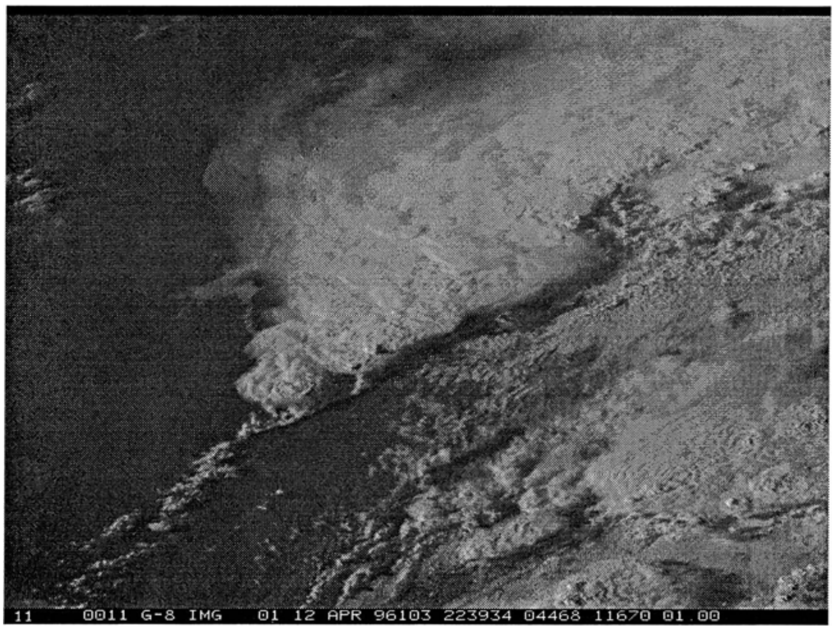

Figure 3.3a. 1 km resolution visible image from April 12, 1996 at 22:39:34 GMT

In Figures 3.3b-3.3f, low, mid and high cloud drift winds from imagery at different times intervals (but for the same time period) are shown. Notice the increase in cloud drift winds as frequency between images is decreased, and that some of the winds from 30 minute interval imagery are clearly in error. Not shown is the ease with which winds were able to be calculated at the different time intervals. According to those tracking the clouds: as time interval grew less, target selection became easier, especially at one minute intervals. The major difference noted between one minute interval and 30 second interval imagery was the ability to follow changes at thunderstorm top, as well as being able to clearly observe vertical growth of the cumulus clouds.

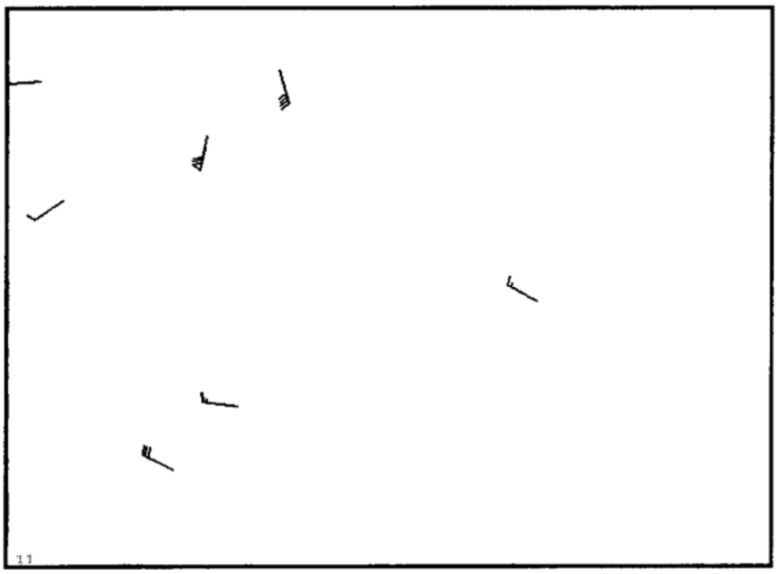

Figure 3.3 b. Cloud drift winds from 30 minute interval imagery over the area in Figure 3.3a.

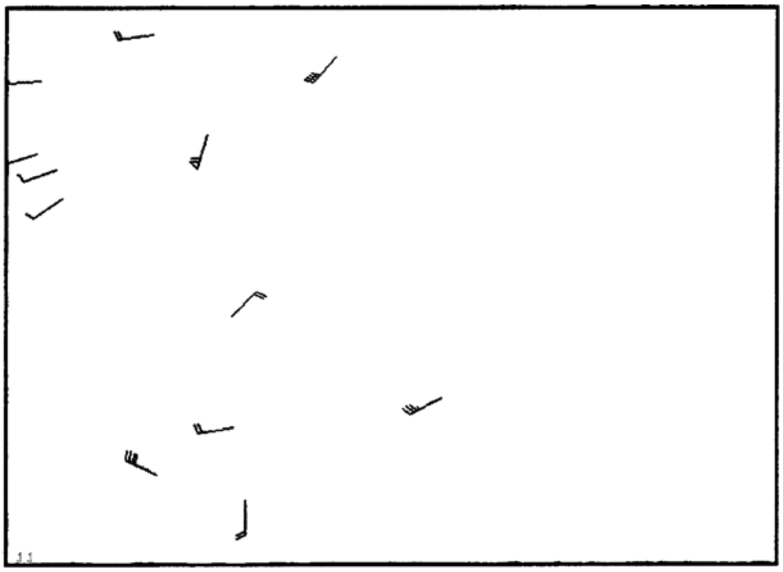

Figure 3.3 c. Cloud drift winds from 15 minute interval imagery over the area in Figure 3.3a.

Figure 3.3 d. Cloud drift winds from five minute interval imagery over the area in Figure 3.3a.

Figure 3.3 e. Cloud drift winds from one minute interval imagery over the area in Figure 3.3a.

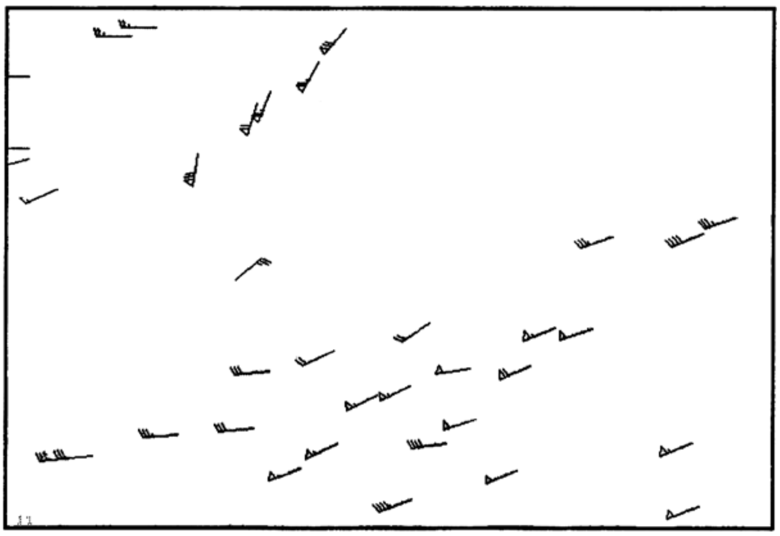

Figure 3.3 f. Cloud drift winds from 30 second interval imagery over the area in Figure 3.3a.

4. POSSIBLE FUTURE ACTIVITY

4.1 Accurate winds beyond the Arctic/Antarctic Circles

Investigations with one minute interval GOES-9 satellite imagery well outside the satellite's 60 degree zenith angle point to the capability to derive highly accurate cloud motions in that region. The possibility of using GOES and AVHRR for cloud height determination with the "least squares stereo" technique makes this an intriguing area for investigation.

4.2 Sub-pixel motions

As shown) in section 3.4 "Example 2: Clouds over Texas with 1 minute sampling" of the companion paper by Campbell et al (1996), there was considerable fluctuation in the image to image wind estimate because of the use of conventional methods of estimating the motion. We believe that great promise lies in reducing round off error by an analysis of the shape of the correlation function used to measure the movement of the cloud. This is especially important in view of the applications with lower resolution data (IR) at higher temporal resolutions.

4.3 Utility of frequent interval imagery and verification of winds

A number of avenues for verification of winds and the general benefit of 30 second to 3 minute interval imagery are underway at CIRA. Joint investigations of one minute imagery with research personnel at the National Hurricane Center (for hurricanes and tropical storms) and National Severe Storm Laboratory (for tornadoes and convection with complimentary Doppler radar data) are in progress. Investigations designed to determine how to optimize very frequent interval GOES satellite observations and Doppler radar data are underway with a number of National Weather Service Science and Operations Officers at various National Weather Service Forecast Offices.

5. CONCLUSIONS

With the new GOES satellites of special imaging sequences have been taken at thirty second, one and three minute intervals. This frequent interval imagery is providing scientists with exceptional observations of atmospheric motion. Research is showing that imagery at such high frequencies are very good for deriving mesoscale cloud motions, even in the most complex of situations. When one minute and 30 second interval imagery is analyzed, clouds are easily followed, the basic question being how many vectors does one want? With imagery at such high frequencies, cloud target identification problems do not exist; indeed vertical growth can be observed in developing cumulus fields. Results point toward cloud drift wind improvements in the future based on geostationary satellites being operated in "special adaptive observing scenarios" to provide dense and highly accurate wind fields in regions of importance, including regions of anticipated model impact.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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