NOTE ON THE STEREO INTERPRETATION OF NIMBUS II APT PHOTOGRAPHY

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ABSTRACT

Nimbus II APT photography, when properly reproduced, i.e., by a modified Westrex photofacsimile or similar high quality recorder, permits excellent stereoscopic viewing of clouds over about 25 percent of the area of adjacent pictures. This satellite system appears to have unintentionally optimized resolution, tonal contrast, the base/height ratio, and exposure interval compared to these parameters of other systems. Theoretically, without cloud motion, cloud heights to an accuracy of about 1 km. can be obtained from the photography. This limit is the equivalent of a 17 m. sec.$^{-1}$ cloud speed along the x-axis of the pictures. In practice cloud heights to an accuracy of about 2 km. are reasonable. An illustration shows clouds at seven different relative heights.

1. INTRODUCTION

For a number of reasons stereo interpretations of cloud pictures obtained from staellites have not been successful in the past. However, recently and belatedly, it was found that the Nimbus II APT pictures, when properly processed, provide excellent stereoscopic viewing. The purpose of this note is to reiterate to the meteorologist the usefulness of stereo photography, and the requirements of picture acquisition and viewing for stereo interpretations, to show why previous photography was relatively poor stereoscopically, and to illustrate the stereoscopic potential of the Nimbus II APT photography.

To keep this paper within the bounds of a brief note for the immediate attention of users of Nimbus APT pictures, the authors had to presume certain knowledge of stereo photography on the part of readers. Those who feel the need for an elaboration of the photogrammetric aspects of the note, such as an explanation of the stereographic geometry and technical terminology used, may be helped by consulting a standard reference [1] on photogrammetry. For example, [1] deals specifically with stereoscopy in chapter 11 of volume 1 and with photography of the earth's surface from satellites in chapter 22 of volume 2.

2. USEFULNESS OF STEREO PHOTOGRAPHY

There can be no question that stereoscopic viewing and investigation of meteorological satellite photography can provide considerably more information than a monocular or single image study of the area photographed. Photo-geologists, photo-foresters, military photo interpreters, and photogrammetists, have long since proven that a three-dimensional study of vertical and high oblique aerial photography can provide them with added recognition of features and feature relationships as well as provide a means of height discrimination and height measurement. For the meteorologist, it provides a means of determining absolute and relative cloud heights; it provides information on slopes and shapes of cloud formations; it can be used to discriminate cloud features from ground features exhibiting the same tonal characteristics; it can be used for the determination of cloud direction and speed. It can be used for the study of cloud dispersion and feature change provided that enough "fixed" surrounding information is available for correct stereo correlation of the two images. Celi et al. [3] have shown that it can be used for the determination of cloud direction and speed when the cloud shadows are viewed on land of known height. In the case of satellite photography, the stereo technique visually illustrates the perspective view of high oblique imaging angles and the effect of earth curvature, both of which might otherwise lead to incorrect interpretation, measurement, and location of cloud formations.

The meteorologist has, in many cases, recognized the value of stereo techniques and has employed them in evaluating terrestrial and aerial photographs of meteorological phenomena, but until recently the taking conditions and types of satellite cloud photographs did not suitably lend themselves to this type of analysis.

3. STEREOSCOPIC ACQUISITION CRITERIA

The most obvious criterion is of course that two images, separated by a distance (stereo base), must be obtained of the same meteorological scene. Acquisition criteria which are not as basic but are of equal importance for comfortable and efficient stereoscopic investigation are:

a. The images should be obtained from approximately

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the same altitude to avoid disturbing height parallaxes *normal* to the stereo base.

b. The images should be of approximately equal scale (to within 10–15 percent) to avoid differential magnification when viewed.

c. For vertical or oblique aerial photographs, the camera axes should be parallel, to approximately 5 degrees, to avoid the necessity for photographic transformation or special viewing procedures.

d. Convergent stereo pairs for which camera axes can include an angle up to about 40 degrees require special viewing devices or transformation before they can be viewed comfortably. Because clouds usually make up a greater percentage of the camera altitude than terrestrial features, convergent photography with large angles is not recommended. Transformation of convergent images is based on a ground reference surface and disturbing viewing effects due to the cloud heights will remain.

e. The stereo-base should normally be 0.3 to 1.0 times the flight altitude for imaging terrestrial and man-made features although base to height (B/H) ratios of up to 1.5 have been used. Theoretically, height detection should increase linearly with increasing B/H ratios but the physical limitation of visually correlating a stereo image when viewing opposite sides of the object (such as towers, trees, steep peaks and slopes, tall buildings, etc.) prevents the employment of these ratios. Experiments have shown that the relatively smooth and rolling features of clouds permit large B/H ratios to be employed. B/H ratios of 1.0 to 1.5 are extremely valuable for the detection of small height differences in small-scale meteorological satellite photography.

f. The images should have minimum geometric distortions to allow parallax-free image registration. Stereo-viewing registration is, of course, not as critical as measurement registration, and distortion control for this purpose need not be as precise as for photogrammetric operations.

g. The stereo images should be of nearly equal image quality, although one high quality image and one poor quality image can form a stereo pair to provide more information than the high quality image alone.

h. Finally, the images should be of nearly the same tonal contrast, and, of course, with as high a contrast as possible without the loss of detail in the gray regions.

4. STEREOSCOPIC VIEWING CRITERIA

Viewing criteria which have not been covered in the discussion on acquisition are:

a. Viewing magnification should be commensurate with the image quality.

b. The images should contain a minimum of visual "noise" such as line structures or a dense network of registration marks.

c. Images should be well and equally illuminated.

d. Complete separation of the two visual "channels" is necessary.

e. Similar images and lines of similar images (epipolar rays) should be rotated to be parallel to each other and parallel to the viewer's stereo base (eye base).

5. SUITABILITY OF EXISTING METEOROLOGICAL PHOTOGRAPHY TO STEREO INVESTIGATION

Unfortunately, none of the satellite acquisition systems has been designed to exploit stereoscopic information, and in the systems where stereo study is possible, the graphic record normally provided to the meteorologist is not suited to good viewing. Following is a brief description of pertinent characteristics of the various systems.

a. TIROS did provide duplicate views of the same cloud features and did have nearly parallel camera axes, but the stereo base was extremely short and when stereo pairs were formed from widely separated images the cloud features appeared drastically different because of the excessive obliquity of the camera axes for the majority of photographs. Scales changed because of the same factors.

The TIROS images were of suitable quality although the resolution was relatively low and the scan-line pattern predominant. Limited stereo studies were performed on TIROS images and provided some research information. It might be interesting to note that the motion of ice masses was determined by Cameron [2] from TIROS imagery by stereoscopically studying and measuring pairs of photographs taken one or more orbital passes apart. Since all the ice was essentially at one level, its component of motion along the x-axis between picture times had the effect of raising or lowering the stereoscopic image. This effect was then mathematically translated into horizontal motion.

b. Nimbus I AVCS pictures did not overlap except in the extreme corners of the oblique frames; therefore they were not suitable for stereoscopic investigation.

c. Nimbus I APT pictures also failed to overlap. Furthermore, their quality was relatively poor.

d. Nimbus II AVCS pictures provide fair stereoscopic viewing over a usable 25 percent overlap on the vertical pictures. These pictures are taken at 91-sec. intervals to give a base length of 515 km. At a mean orbital height of 1180 km., the B/H ratio becomes 0.44. This value is low for optimum analysis. Furthermore, in the oblique pictures, the effective H increases as H/cosine of the nadir angle to give still lower B/H ratios. Generally low contrast, noise in the pictures, and the difficulties of feature location associated with oblique viewing and measurement all combine to make stereoscopic analysis difficult.

e.. Nimbus II APT system provides images well suited to stereo investigation and therefore is the reason behind this note, but because the system was not designed to exploit this tool, only limited stereo coverage is possible.

The vidicon format of 11.2 mm. square with a 6.0-mm.

focal length provides a lateral and forward coverage angle of 86 degrees. The time interval between exposure of 208 sec. provides a stereo base of approximately 1500 km. and therefore a base to height ratio of 1500 km./1180 km.= 1.27. Unfortunately this coverage and stereo base provide only a 26 percent stereo-overlap vs. the 50 percent needed for complete stereo coverage.

The graphic records used in the stereo analysis were 6.6X enlargements to 74 mm. square Polaroid transparencies for stereo projection, and positive paper prints for table-top viewing with a pocket stereoscope. These Polaroid enlargements were obtained from a modified Westrex photofacsimile receiver, AN/GXC–4R759. The modification consisted of adaption to the 800-line picture scan and a reduction of its retrace time from 15 percent to 5 percent. In practice, the prints are ready for desk viewing in a minute or two and the transparencies can be placed in projectors after about three minutes. Group viewing of the projected image requires the use of polarized glasses. The Fairchild paper facsimile records were entirely unsuited for stereo viewing because of the loss of the fine detail and because of the low contrast range.

The original 800-line resolution image, approximately 36 lines $mm.^{-1}$ on the vidicon, becomes, on the print, approximately 5.5 lines $mm.^{-1}$ which is the visual limit of the unaided eye.

A stereo presentation of the 26 percent overlap area is illustrated in figure 1a. These pictures show cloudiness over the northeastern United States and Canada. North is toward the left. A weak Low was centered one-third of the distance down from the top of the picture and near the left margin. Its accompanying cold front trailed southwestward into the clear slot between 8 and 9 of figure 1b. Clouds of interest whose locations are keyed in figure 1b. are:

1. Cirrus and cirrostratus.
2. A cirrus band which crosses other clouds in a N–S direction.
3. Cumulonimbus tops at or slightly above the cirrus.
4. A middle-level layer with slight variations in cloud top height.
5. Low stratus and stratocumulus.
6. An isolated towering cumulus mass which rises well above the surrounding clouds.
7. Middle-level cloud bands.
8. Low-level cumulus lines.
9. Several isolated clouds above and detached from 10.
10. Wave clouds at the same level as the white stratocumulus mass just to the west.

The order of ascending levels may be given as: 5; 8; 10; 9 and 7 and 4; 6; 2 and 1; and 3.

Observations and conclusions regarding the photography are:

1. The stereo base is not excessive for the purpose.
2. The quality of the image is not a limiting factor as previously shown by Kohler [4]. His studies on reconnaissance techniques have shown that both similar image and stereo image integration can improve the Modulation Transfer Function of the resultant image. Since it is very improbable that scan lines on each satellite picture would exactly cover the same image feature, the stereo integration of the photographs appears to improve the viewed resolution and definitely improves the image contrast.

Since the eyes favor relatively high contrast at image edges for stereoscopic registration, it is sometimes difficult to register images on which higher-resolution but lower-contrast, "fuzzy" edges are recorded. Therefore electronically generated, lower-resolution, tone-range-limited images are often easier to register. In the Nimbus II APT system, the tonal range (from black to white) and resolution appear to have been optimized for stereo correlation.

3. The geometry of the earth's curvature is quite apparent in the stereo pairs.

f. ESSA II APT receiving and viewing equipment is the same as that for Nimbus II APT. The acquisition system in ESSA II is also very similar to that of Nimbus II: 11.2-mm. square format, 5.7-mm. focal length, 800-line system. The ratio of $B/H=\frac{2530 \text{ km.}}{1400 \text{ km.}}=1.8$ indicates a favorable stereo condition although preliminary experiments have shown that Nimbus II APT provides a better record for this purpose. In the Nimbus II APT system the lower altitude provides a scale, i.e., cloud resolution, improvement of 1.3X, which perhaps is the determining factor under otherwise near-equal conditions.

6. PHOTOGRAMMETRIC INVESTIGATION

In the formula for determining the minimum detectable height differences by stereoscopic measurement:

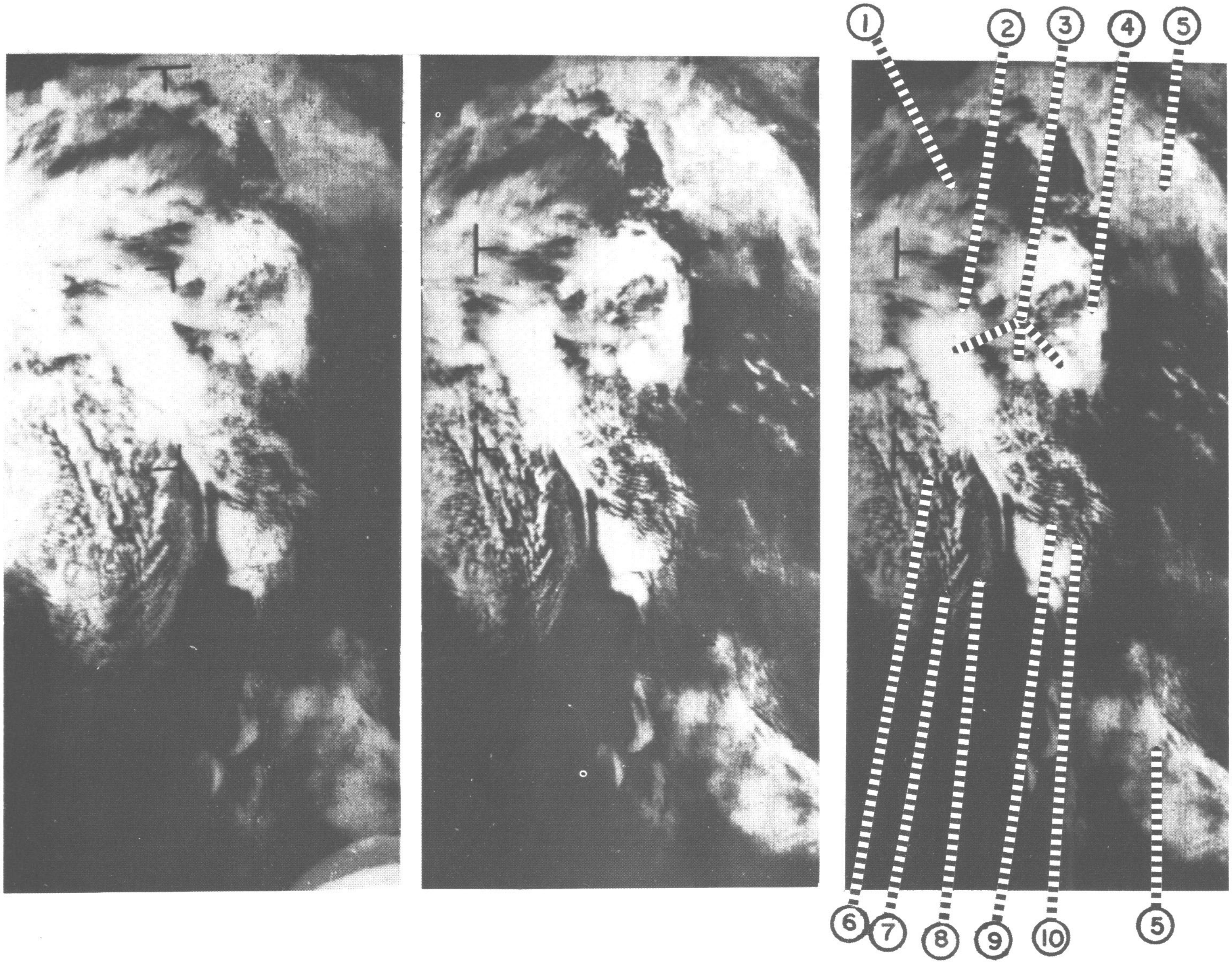
$$\Delta h=\frac{1}{\theta \times m \times 5 \times R}$$

where

Δh=minimum detectable height
$\theta=B/H$ ratio=1.27
m=image scale=1:30,000,000
R=resolution in lines $mm.^{-1}$=5.5 $mm.^{-1}$
5=empirically determined measuring and pointing factor.

Δh on the enlarged (74 mm.×74 mm.) Nimbus APT photograph is approximately 1 km. This theoretical number is quite logical as the approximate ground resolution is 5 km. and heights are normally determined to approximately a factor of 5 better than horizontal image detection. In actual practice height determinations to an accuracy of about 2 km. can be expected.

Cloud displacement which could provide speed and direction of cloud motion can be detected to approximately the same sensitivity provided the same cloud feature is positively identified and the point of measurement is of



a b

FIGURE 1.—(a) Stereo pair enlarged 2X from Polaroid prints. Nimbus II APT, orbital pass 790, 1541 GMT and 1537 GMT, July 13, 1966. (b) Key to clouds of interest in (a).

high image quality and contrast. With stereo as the technique, clouds which have moved 3.5 km. during the 208-sec. exposure interval of Nimbus II can be "monitored." This amounts to a cloud speed of 17 m. sec.$^{-1}$ The determination requires that a fixed reference, such as a terrestrial feature, be visible for measurement. To obtain winds in this way, cloud heights must first be determined by other means, except when the cloud motions are normal to the stereo base. In this case the height parallax can be directly translated into cloud motion in that component.

Other photographic means of determining cloud heights, when cloud motion exists, would require simultaneous stereo pictures and complicated systems of satellites.

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