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MONTHLY REPORT

for

JUNE 1978

VISSR Atmospheric Sounder (VAS)
Development and Performance Evaluation

Contract No.: NAS5-21965

Prepared by

Space Science and Engineering Center
University of Wisconsin
Madison, WI

for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD

I. General

On June 27, 1978, P. Menzel of SSEC went to Davis, California, to give a presentation on "A Man Interactive Technique for Specifying Cloud Heights from Sounding Radiance Data" at the Third Conference on Atmospheric Radiation. A preprint of that paper is submitted with this progress report.

II. Data Processing System Development

Work on the Data Base Manager is proceeding. Circuit board construction is nearly complete, the asynchronous interface is constructed, conversion to multiwire boards has been undertaken where advantageous, and maintenance improvements have been engineered into the DBM configuration. The major hardware components (midi computer, magnetic tape unit, disc and controller, and CRT) have been linked together and checked out. The lower level software of the disc management system is being integrated into the DBM. Higher level data base management system software is being written and tested. Communications protocol is under consideration. The accumulation of parts for the Applications Processor and the VAS User Terminal is complete and construction of associated circuit boards continues.

The TIROS-N receiving system nears completion at the "Day 1" level. We expect to be able to ingest, preprocess, and archive HIRS-2 and MSU data from the TIROS-N Information Processor at launch. Construction of the antennas on the roof is complete and additional supports are being added to reduce swaying in excessive winds. The antenna control interface hardware awaits the insertion of digital-to-analog convertors so that final testing will be completed. The testing of the microprocessor to magnetic tape unit communications interface has been delayed somewhat with the redesigning of one of the circuit boards. Testing will follow shortly. Insertion of software for orbit determination and antenna pointing in an operational scenerio is underway.

III. Development of VAS Data Processing Techniques

Preparation of a data set has begun for testing the Australian Numerical Meteorology Research Center regional forecast model. Application to this model of high resolution man-interactive soundings from several Nimbus 6 orbits over the U.S. is planned. This model approaches the mesoscale with its 60 km grid.

The evaluation of a clear column radiance retrieval algorithm developed at NESS has begun. The algorithm uses the paired field of view N* approach without any microwave information. Since VAS will not have microwave instruments on board, this investigation is very relevant. With the aid of interactive processing, the testing of this experimental TOVS technique should offer new insights.

More detail on these and other activities is available in the attached NESS activities report.

SPACE SCIENCE AND ENGINEERING CENTER

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10 July 1978

Mr. J. B. Connor
Contracting Officer, Code 289
NASA--Goddard Space Flight Center
Greenbelt, MD 20771

Dear Mr. Connor:

In accordance with Article III of Contract NAS5-21965, I am submitting the required Progress Report for the month of June 1978.

If you have any questions or desire further information, please contact me at (608) 262-0118.

Sincerely,

Paul Menzel

Paul Menzel
Program Manager

WPM/rmk

Enclosure

cc: H. Montgomery, Code 942 (10 copies)

QUARTERLY ACTIVITIES REPORT

April - June 1978

1. Interactive Retrieval Development (Hayden, Woolf, Nagle, Smith)

a) A reflected solar radiation correction for the shortwave (4.3 μm) CO_2 channels was tested on two noontime orbits over the U.S. where strong solar contamination was suspected. The correction is based on the difference in window channel brightness temperatures measured at 3.7 and 11 μm. As formulated, corrections rarely amount to more than 1 degree for 2190 cm^{-1}; 0.5 degrees for 2212 cm^{-1}; and are negligible for more opaque channels. Nevertheless, the corrections have measurable impact on low level temperature retrievals though it has not been determined if the accuracy is improved.

b) A major effort was directed to simplifying and to increasing the speed and efficiency of principal software in the man-interactive processing. Although considerable progress has been made to improve the procedures for real time processing, still further optimization is required.

c) Software has been developed to merge data sets produced on the McIDAS. As a consequence, objective analyses using several orbits of satellite data with or without radiosonde data can now be accomplished.

d) A new procedure has been developed which enables the use of microwave-only produced temperature profiles in heavily clouded areas. Systematic differences between the infrared and microwave retrievals are eliminated by adding a correction based on the difference between infrared and microwave retrievals in the vicinity of the cloud. The correction prevents false gradients between the infrared and microwave retrievals caused by the different coefficients applied to each type of sounding.

e) A routine has been checked out to remap polar orbiter data into the projection viewed from a geostationary satellite with subpoint at arbitrary longitude. The routine allows "zooming" to any desired magnification. The next step in development is to provide linkage to other retrieval software which will allow man-interactive retrievals using the remapped raw data. The remapping allows for simultaneous production of winds and soundings from the amalgamated polar orbiting satellite sounding data and the geostationary satellite imagery.

2. Hardware Proposal and Development Support (Smith, Howell, Woolf)

a) Progress continues on the four phases of direct readout data receipt for TIROS-N: i) the TIROS-N antennas have been installed on the roof of the Meteorology and Space Science Building, and the receiving system is near completion; ii) the antenna control interface hardware needs only the addition of digital-to-analog converters before final testing can be accomplished; iii) with a recent increase in SSEC engineering support, work has begun on the interface between the microprocessor and the receiving system; iv) under current plans, a magnetic tape controller built by SSEC for a different archival system will be used in the TIROS-N system, and the duplication of that hardware is nearly complete. It is expected that the direct readout system will be ready for "Day 1" operation with the data ingest and archival limited to the TOVS (HIRS-2 and MSU) data. The ingest and archival of APT data will be added as soon as possible.

b) The simulation of a two-channel partial interferometer with a single 15 μm band spectral filter and two delay regions showed minor improvement over the single delay region. The simulation of partial interferograms from line-by-line calculations of CO_2 transmittance in the 4.3 μm band continued in an effort to define an appropriate combination of input spectral region and appropriate delay region. Investigation of the 4.3 μm spectral region will continue using subintervals of the 2160 to 2400 cm^{-1} region and the corresponding delay regions.

As a result of the dramatic improvement (as revealed by simulation studies) in sounding accuracy using the interferometric approach over that achieved by contemporary spectral radiance observing techniques, a proposal for financial support of further development has been submitted to NASA. The proposed effort would lead to the construction of an engineering model of an interferometric sounder which would be tested aboard the NASA CV-990 aircraft.

3. Meteorological Studies (Hayden, Smith)

a) The 23 August 1975 European satellite data which was criticized by NMC in their evaluation of DST-5 was minutely re-examined using man-machine interactive methods. While it was generally possible to delineate the strong baroclinic regions in good detail, the problem noted by NMC of depicting the major trough too far to the east persisted. With current methods, the retrievals are apparently unreliable over cloudy, high terrain and for this case the difficulty was aggravated by poor coverage (between orbits) in the critical area. The immediate solution is to edit out the bad retrievals (either infrared or microwave) which result in such areas. The erroneous retrievals are easily detected from the excessive thermal winds they induce and procedures have been developed to enable the man to check the retrievals using such a meteorological consistency check. Also, images of the 6.7μ water vapor channel dramatically illustrated the utility of this measurement in locating the moisture tongue on the south side of a strong polar jet.

b) Meteorological Applications of Satellite Indirect Soundings II prepared by the Department of Meteorology under NOAA Grant 044-153-2 is in print and available.

c) August 19-20 has been chosen as a first case for application of high resolution man-interactive soundings to the ANMRC regional forecast model. The first data set from three orbits over the U. S. is nearly complete and should be sent shortly.

4. <u>Support of NESS Sounding Operations</u> (Hayden, Woolf)

a) Images of a warm, moist scene in the 4.3 μm band showed that the current HIRS limb correction technique is not giving a smooth point-to-point transition in brightness temperatures. A considerable improvement was achieved by including the ~~cosine~~ secant of the zenith angle as a predictor in the regression coefficients used to make limb corrections. This result was forwarded to the Sounder Steering Group as a possible modification for TIROS-N software.

b) A memorandum of agreement between the MAB and the Office of Operations has been prepared for the proposed man-interactive enhancement of TIROS-N soundings during the FGGE special observing periods. At present, the purchase of a terminal for MAB use with the backup VIRGS is in the procurement cycle.

c) The MAB has agreed to use the McIDAS interactive sounding capabilities to evaluate experimental improvements to TIROS-N sounding software developed by other components of NESS. Results from an experimental clear radiance technique proposed by McMillan have been tested on the August 25 orbit previously processed on McIDAS. The experimental method performs very well in the 15 μm band but is somewhat erratic in the 4.3 μm band.

d) Several data sets of Nimbus 6 data formatted to look like TIROS-N data have been prepared and provided to NESS operations to be used for checkout with the TIROS-N processing system.

A MAN INTERACTIVE TECHNIQUE FOR SPECIFYING CLOUD HEIGHTS FROM SOUNDING RADIANCE DATA

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1. INTRODUCTION

The determination of cloud heights is important for many meteorological applications, including the estimation of the pressure-altitude of winds obtained by tracing clouds from satellite imagery. Several methods for determining cloud heights using satellite data have been developed over the years. One method (Fritz, 1962) compares the IR window channel brightness temperature with a vertical temperature profile in the area of interest to obtain the height of the cloud. This IR window cloud height determination assumes that the cloud is opaque and fills the satellite instruments field of view, and thus it works fine for dense stratoforms of cloud. However it is inaccurate for semi-transparent cirrus clouds and small element cumulus clouds. A second method (Mosher, 1976, and Reynolds and Vonder Haar, 1977) improves the IR window channel estimate of a cloud top height by allowing for fractional cloud cover and by determining the cloud emissivity from visible reflectance data. Using a multiple scattering model the visible brightness of the cloud is used to calculate the optical thickness, from which the infrared emissivity of the cloud can be computed. Although this "bi-spectral" method is an improvement over the first method, it is still inaccurate for semi-transparent cirrus clouds. The third method (Smith, 1970, 1976, 1978) combines IR window channel data with CO_2 absorption channel data to specify a cloud height. As derived from the radiative transfer equation, cloud pressure is determined from the ratio of the deviations in cloud produced radiances and the corresponding clear air values for two or more spectral channels. This multispectral CO_2 absorption method does not suffer from any of the previous assumptions and thus, in principle, works on all cloud types. However, since one is using the differences of large quantities to provide the cloud height estimate, the results from applying this method to real data can be noisy, especially for low clouds.

We present here a man interactive technique for specifying cloud heights using the CO_2 absorption method. Sample results have been obtained from the application of this technique on HIRS (High resolution Infrared Radiation Sounder) data from Nimbus-6 using the University of Wisconsin McIDAS (Man-computer Interactive Data Access System). Man interaction allows selection of specific cloud elements (those for which associated wind vectors are to be computed), checking for consistency in the resulting cloud height fields, and editing of erroneous results. The cloud heights are determined to a high horizontal resolution (30 km x 30 km) which allows parts of a cloud formation to be traced. The vertical resolution achieved is roughly 50 millibars. The technique is well suited to provide operational support using data from the HIRS instruments on TIROS-N for the specification of the heights of cloud motion winds determined from geostationary satellite imagery.

2. THE CO_2 ABSORPTION METHOD

As derived by one of the authors in his earlier work (Smith, 1970), the ratio of the deviations in cloud produced radiances, $I(\nu)$, and the corresponding clear air radiances, $I_{cl}(\nu)$, for two spectral channels of frequency ν_1 and ν_2 viewing the same field of view can be written

$$\frac{I(\nu_1) - I_{cl}(\nu_1)}{I(\nu_2) - I_{cl}(\nu_2)} = \frac{\varepsilon_1 \int_{P_s}^{P_c} \tau(\nu_1, p) \frac{dB(\nu_1, T(p))}{dp} dp}{\varepsilon_2 \int_{P_s}^{P_c} \tau(\nu_2, p) \frac{dB(\nu_2, T(p))}{dp} dp} \quad (1)$$

ε is the cloud emissivity, P_s is the surface pressure, P_c is the cloud pressure, $\tau(\nu,p)$ is the fractional transmittance of radiation of frequency ν emitted from the atmospheric pressure level (p) arriving at the top of the atmosphere (p=0), and $B(\nu, T(p))$ is the Planck radiance of frequency ν for the temperature $T(p)$. If the frequencies are close enough together, then $\varepsilon_1 \sim \varepsilon_2$, and one has an expression by which the pressure of the cloud within the field of view (FOV) can be specified. The left side of equation (1) can be measured, if the clear radiances are inferred from neighboring clear FOVs,

$$\text{left (1)} = \gamma(\nu_1,\nu_2) \quad . \tag{2}$$

If the atmospheric temperature profile and the profiles of transmittance for the two spectral channels are known, the right side of equation (1) can be calculated assuming P_c,

$$\text{right (1)} = f(\nu_1,\nu_2, P_c) \quad . \tag{3}$$

The optimum cloud height is determined when the absolute difference $|\gamma(\nu_1,\nu_2) - f(\nu_1,\nu_2,P_c)|$ is a minimum.

There are two basic assumptions inherent in this method: (a) that the cloud has infinitesimal thickness, and (b) that the cloud emissivity is the same for the two spectral channels. As reported elsewhere (Smith and Platt, 1978) the maximum possible error caused by assumption (a) is one half the cloud thickness. Errors of approximately one half the cloud thickness occur for optically thin clouds (integrated emissivity roughly less than .6); for optically thick clouds (integrated emissivity roughly greater than .6) the error is smaller, typically one-fourth the cloud thickness or less. Errors due to assumption (b) can be minimized by utilizing spectrally close channels.

Once a cloud height has been determined, an effective cloud amount can be evaluated from the IR window channel data using the relation

$$N\varepsilon = \frac{I(w) - I_{cl}(w)}{I_{Bcd}(w) - I_{cl}(w)} \tag{4}$$

N is the fractional cloud cover within the FOV, w represents the window channel frequency, and $I_{Bcd}(w)$ is the opaque cloud radiance. $I_{Bcd}(w)$ is evaluated with the Planck function $B(w, T(P_c))$, where the temperature, T, is associated to the cloud pressure, P_c, by a mean temperature profile for the given FOV.

3. UTILIZATION OF THE HIRS AND SCAMS DATA

The HIRS instrument, which is aboard the Nimbus 6 satellite (and will be aboard the TIROS-N series of operational satellites), possesses 16 different IR channels in addition to the visible channel. The instrument scans from left to right along the orbital track, each scan consisting of 42 contiguous fields of view with 30 km x 30 km average spatial resolution. The channels that are most cloud sensitive and thus most useful for the CO_2 absorption method have the following central wave numbers: 702, 716, 733, 749, 900, and 1224 cm^{-1}. Using ratios of spectrally close channels, four separate cloud heights for the same cloud layer can be determined (702/716, 716/733, 733/749, and 749/1224). For a given height, the IR window channel at 900 cm^{-1} is used to evaluate an effective cloud amount.

In addition to the HIRS instrument, these polar orbiters also have a SCAMS (Scanning Microwave Spectrometer) instrument on board. The SCAMS on Nimbus-6 had five microwave channels of 200 km spatial resolution. The oxygen sensitive channel of frequency 53.850 GHz senses the mean temperature of the troposphere, and thus it it extremely useful for interpolating clear FOV IR channel radiances to adjacent cloud obscured FOVs. Specifically to determine individual clear radiances in a cloud obscured FOV, we select two nearby clear FOVs which are across the microwave response gradient and use the microwave data to interpolate the IR channel responses from the clear FOVs to the adjacent cloudy FOV.

4. DESCRIPTION OF MAN INTERACTIVE TECHNIQUE

After identifying a cloud of interest, the man views the visible, 11 μm, and the difference of the 3.7 μm and 11 μm windows to identify clear FOVs in the vicinity of the cloud (see figure 1). Viewing the microwave data, he then selects two clear FOVs across the microwave response gradient (see figure 2). At each FOV, atmospheric temperature and water vapor profiles are retrieved from all the microwave sounding data and a transmittance for each IR spectral channel is evaluated from that temperature profile and a corresponding water vapor profile.

Next, the man selects a FOV in the cloudy region of interest and calculates $\gamma(\nu_1,\nu_2)$ from observations of $I(\nu)$ and interpolations of $I_{cl}(\nu)$. Also, $f(\nu_1,\nu_2, P_c)$ is evaluated at many cloud heights using interpolated temperature profiles and transmittances. Using the four IR ratios, four cloud height determinations are made. Less than four are made if $I - I_{cl}$ for

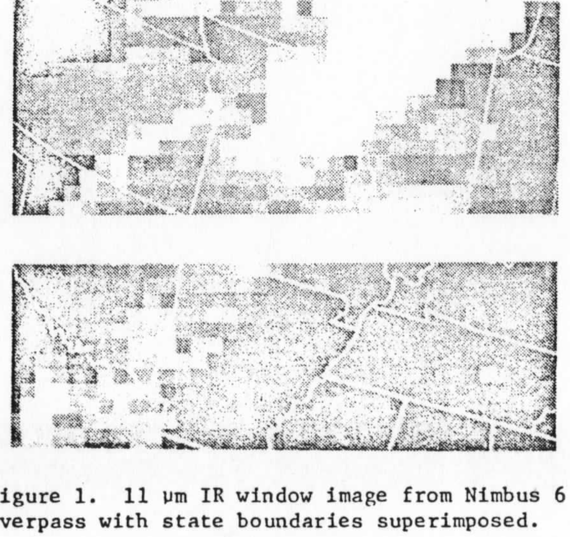

Figure 1. 11 μm IR window image from Nimbus 6 overpass with state boundaries superimposed.

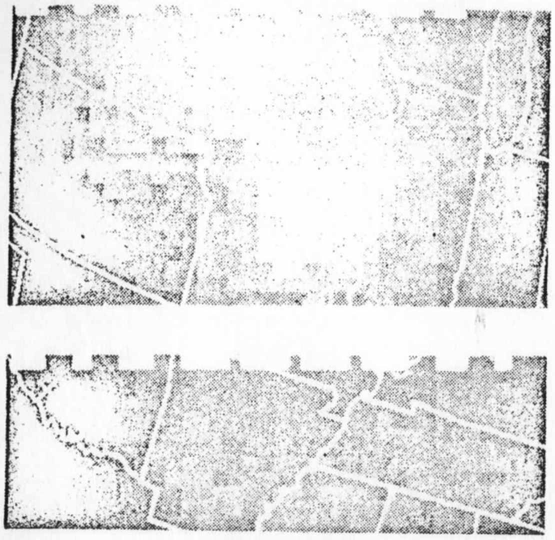

Figure 2. Microwave image from Nimbus 6 overpass with two clear FOVs selected across microwave response gradient.

given channels are within the noise response of the instrument and thus should be rejected. Using the IR window and as many as four cloud heights, as many as four effective cloud amount determinations are made. If a cloud amount is less than 40% the corresponding cloud height is automatically rejected as unreliable. To select the most representative cloud height P_{ck}, the algorithm checks the frequency of occurance and constructs the matrix of differences

$$[(I - I_{cl})_i - N\varepsilon_k \int_{P_s}^{P_{ck}} \tau_i dB_i] = M_{ik} \qquad (5)$$

P_{ck} is chosen if it occurs more than once or when $\sum_{i=1}^{5} M_{ik}^2$ is a minimum. (The sum omits the IR window channel which is used to evaluate the effective cloud amount).

In this way a field of cloud heights is generated (see figure 3). Inconsistent heights can then be edited out. After the initial selection of the two clear FOVs, each cloud height determination requires about one second.

5. RESULTS

Table I shows the comparison of cloud top pressure determinations for a Nimbus 6 North American overpass on August 25, 1975 obtained by (a) the IR window method using Nimbus-6 derived soundings, (b) the bi-spectral method (Mosher, 1976) using climatological soundings, (c) the multi-spectral CO_2 absorption method, and (d) radar echoes. The radar information follows the Nimbus overpass by 15 minutes, so the comparison is nearly coincident in time. The cloud heights were evaluated in the area of deep convection centered over Iowa, Illinois, and Missouri (see figure 1). Pressure altitudes obtained by the CO_2 absorption method are typically within 50 millibars of the radar echo determinations, and they also show similar

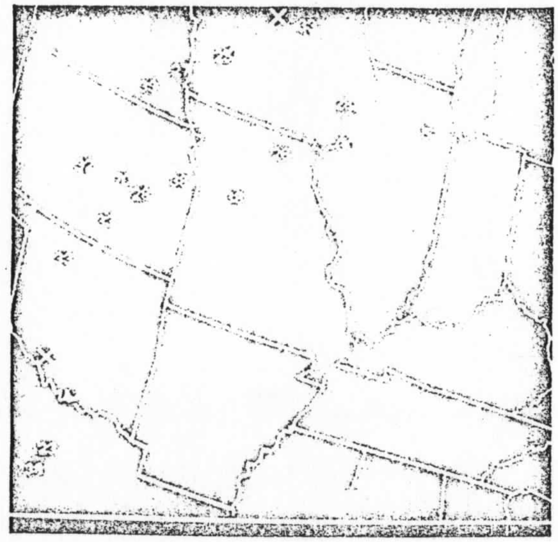

Figure 3. An example field of cloud heights (in centibars).

Table I. Summary of Cloud Top Pressure Altitudes (in millibars) for North America obtained by IR window (a), bi-spectral (b), and CO_2 absorption methods (c) and by radar (d).

a	b	c	d
260	250	310	310
310	300	260	230
290	280	250	190
480	530	390	380
310	310	330	380
730	860	510	590
280	270	330	400
270	260	330	240
300	290	240	150
450	490	380	480

agreement with the bi-spectral method determinations.

Figure 4 shows the comparison of the bi-spectral and CO_2 absorption methods going from inside the dense cumulus clouds over Missouri out along the cirrostratus clouds over Kansas, Oklahoma, and Texas blowing off the tops of the thunderstorms (see figure 1). As one moves away from the dense cumulus clouds towards the thin cirrus, the CO_2 absorption method maintains high altitudes for the cirrus while the bi-spectral method underestimates the altitude. This occurs because the IR window senses radiation from within and below the thin clouds and thus its brightness temperature is an overestimate of the cloud temperature.

For low lying clouds (found just north of the cirrus over Kansas in figure 1) the CO_2 absorption heights are found to be low but lacking the consistency of the IR window or bi-spectral heights. This difficulty arises because the clouds are warm and low, and therefore the difference of the cloudy and cloud corrected FOV

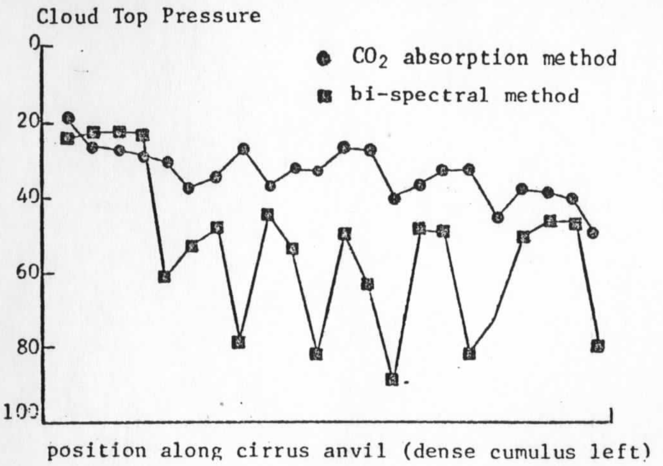

Figure 4. Cloud top pressures (in centibars) plotted versus the position along the cirrus anvil emanating from the dense cumulus center.

radiances are close to the noise level of the instrument.

Table II shows data for a Nimbus 6 European overpass on August 23, 1975. The fourth column shows cloud top pressures inferred from radiosondes, and the first three columns show pressures determined by the IR window, bi-spectral, and CO_2 absorption methods respectively. The radiosondes were released two hours after the Nimbus overpass. Radiosonde temperature and dew point observations are used to obtain a relative humidity profile, and the existence of clouds can be diagnosed since the relative humidity is relatively high within cloud layers. The cloud heights were evaluated along an intense upper level jet stream (see figure 5). In view of the difficulty of estimating high level cloud tops from radiosonde data, the good agreement between the CO_2 absorption and radiosonde data is encouraging.

6. SUMMARY

A man interactive application of the multi-spectral CO_2 absorption method has been developed and the results of two case studies have been demonstrated. The method has been shown to yield reliable cloud pressure altitudes for most clouds, even relatively thin cirrus clouds. These results allow us to conclude that the CO_2 absorption method should have applications in the amalgamation of polar orbiter and geostationary satellite data to provide improved altitudes of upper tropospheric wind estimations from cirrus cloud motions.

Table II. Summary of Cloud Top Pressure Altitudes (in millibars) for Europe obtained by IR window (a), bi-spectral (b), and CO_2 absorption (c) and by radiosonde (d).

a	b	c	d
560	680	340	300
520	480	350	400
430	400	340	300
600	610	330	300
360	310	330	300
390	360	270	400
730	750	350	300
800	840	850	500
860	970	620	700

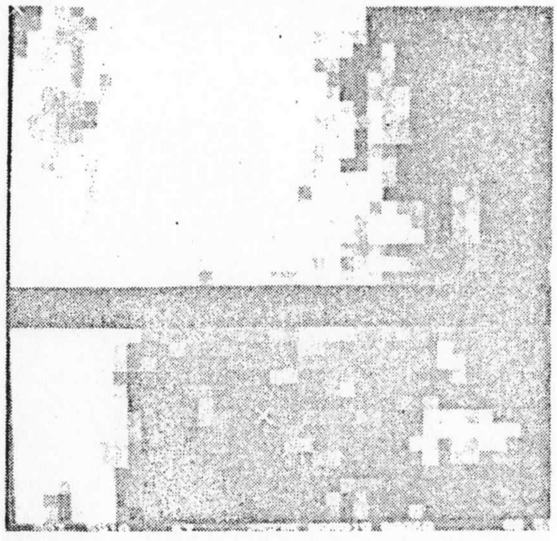

Figure 5. Image of the difference of the 11 μm less the 3.7 μm IR window channels for the Nimbus 6 European overpass. Cloud height determinations (in centibars) are superimposed.

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