

## SNOW/CLOUD DISCRIMINATION SENSOR

by

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Distinction between snow and clouds as seen from satellite photos has long been a problem for users of remotely sensed data. For the hydrologist, snow obscured by cloud and the problem of determining which is which under a variety of conditions makes accurate snowmelt and runoff forecasts difficult. Improved distinction between snow and clouds is also valuable for groups monitoring global snowcover extent, such as the satellite-derived NOAA/NESS Northern Hemisphere Snow and Ice Boundaries weekly charts (figure 1). For the climatologist the problem presents itself in terms of determining the distribution and frequency of cloud on varying spatial and temporal scales. Computer models simulating global climate are still weak in the area of atmosphere-surface interactions (GCMs), and especially in parameterizing the relationships between surface and planetary albedo in the vicinity of the major cryospheric boundaries (EBMs).

The potential for discrimination between snow and clouds using a near infrared satellite sensor was first noted in 1975 when observations in the near infrared beyond 1.3  $\mu\text{m}$  became available. O'Brien and Munis (1975) reported laboratory results showing a marked drop in reflectivity of snow in the near infrared region, most notable in 1.5-1.6  $\mu\text{m}$  and 1.95-2.0  $\mu\text{m}$  bands (figure 2). Skylab was the first satellite to gather data in this part of the spectrum. Using Skylab's Earth Resources Experimental Package (EREP) data, Barnes, Smallwood and Cogan (1975) found that Band 11 (1.55-1.75  $\mu\text{m}$ ) showed a definite "black-snow" effect while liquid water clouds remained highly reflective. Valovcin (1976) noted that ice clouds are not as reflective as water clouds, but stressed that the 3 signals should be significantly different in most cases to allow accurate discrimination in the slightly narrower 1.5-1.6  $\mu\text{m}$  band. These results were confirmed by comparing bands 6 and 7 (visible) and band 11 (near infrared) Skylab data for several cases.

The first work towards an operational "snow/cloud discrimination" sensor began in 1976 when the Air Force collected signatures of snow and cloud backgrounds in the near infrared from a series of aircraft flights (Sandford et al., 1976). A detailed spectral analysis of the aircraft data led to the design of a sensor by Westinghouse Electric Corporation in the 1.51-1.63  $\mu\text{m}$  band (Stebbins, 1978). This sensor was flown on board a Defense Meteorological Satellite Program (DMSP) near-polar orbiting satellite during 1979. The purpose of this study was to evaluate the data from this sensor in its present form to determine its worth for improving snow and cloud interpretation from satellite photos and related impacts to climate studies.

DMSP DATA

Between July and December of 1979, the U.S. Air Force flew an experimental snow/cloud discrimination sensor on board one of its DMSP satellites. The sensor collected reflected solar energy in a narrow portion of the near-infrared region of the spectrum (1.51-1.63  $\mu\text{m}$ ), where snow and clouds have significantly different reflectivities (see figure 3, Kimball 1979). Snow appears relatively "black," enabling

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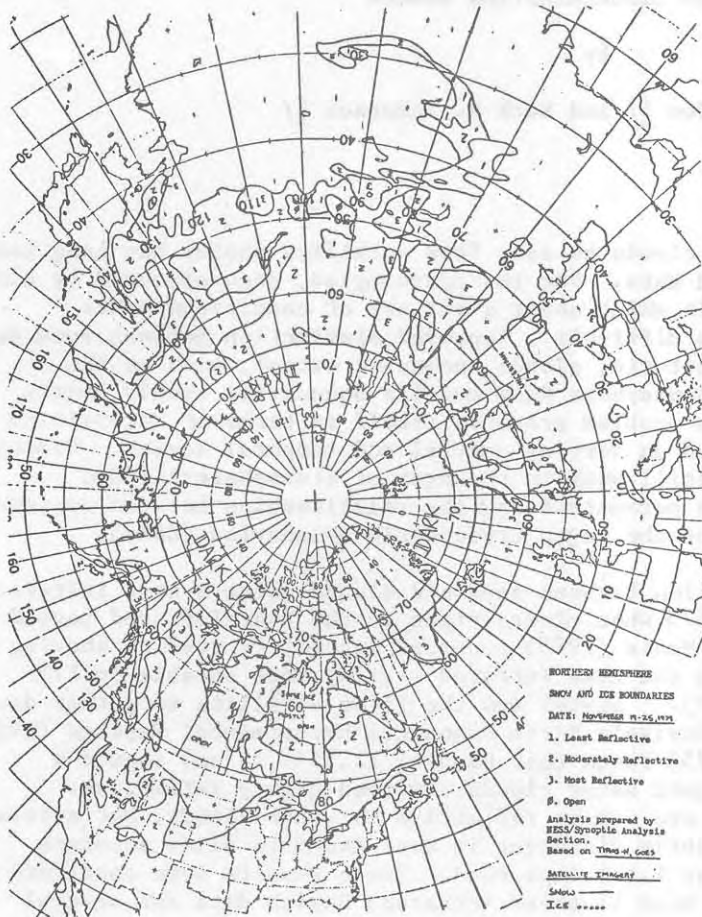
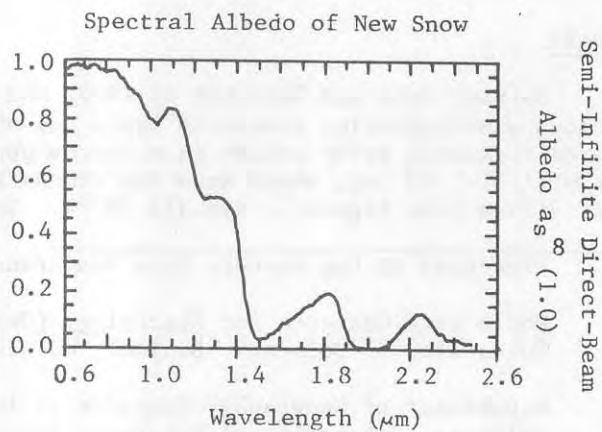


Figure 1.  
NOAA/NESS Northern Hemisphere  
Snow and Ice Boundaries for  
19-25 November 1979

Figure 2.  
Spectral albedo of new snow  
(O'Brien and Munis, 1975)



it to be distinguished from typical water clouds which appear bright since they reflect the majority of incident solar radiation they receive, just as in the visible wavelengths.

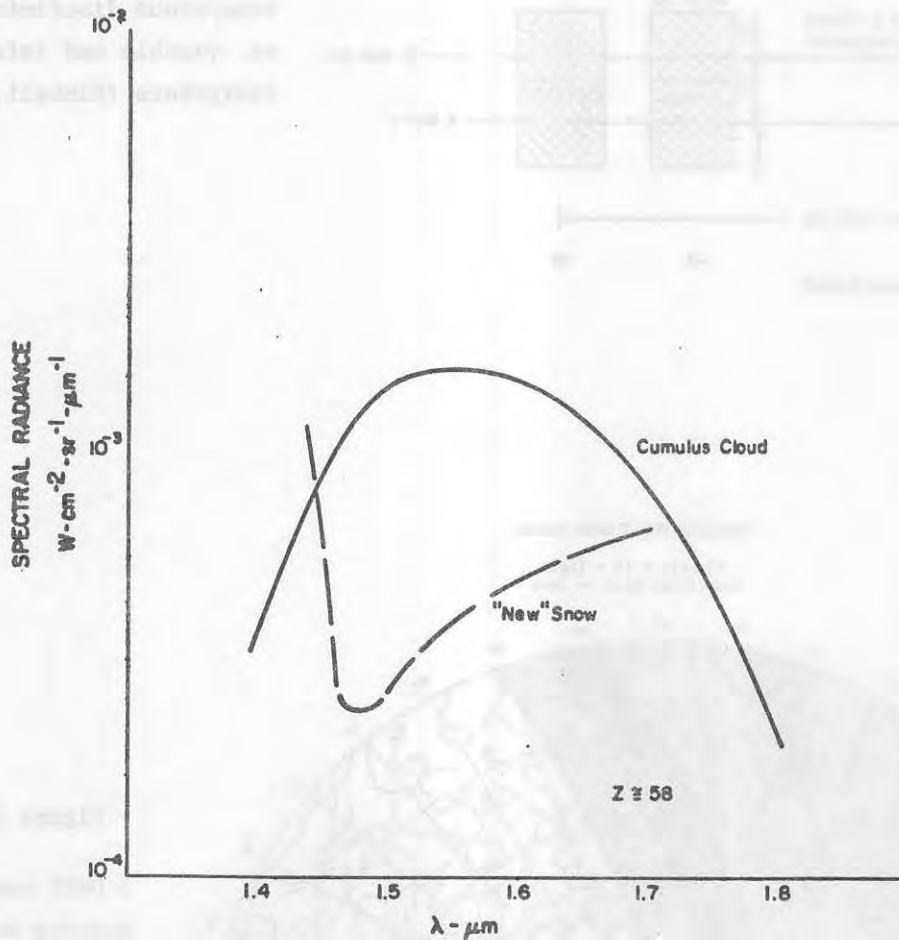


Figure 3. Near-infrared radiances of snow and cloud ( Kimball,1979)

Initial results from the sensor designer (Westinghouse Electric Corporation, Kimball, 1981) and Air Force Global Weather Central (AFGWC) (Woronicz, 1981) suggest that the design performance was essentially as expected. These analyses were performed by pixel by pixel or digital comparisons between the experimental and conventional data. Woronicz (1981) found that the snow/cloud discriminator made correct snow/no snow and cloud/no cloud decisions approximately 90% of the time. Kimball (1981) found similar results. Such analyses are especially well suited for recommendations concerning fully automated, multi-channel digital processing models like those at AFGWC. It was our intent to evaluate the potential for comparing the experimental data, in its present form, with conventional imagery on a non-digital basis. It was readily apparent to us that it could be some time before a revised snow/cloud discriminator sensor could be implemented on a new set of satellites and provide operational results for modelers. We felt there was a possibility that the experimental data could provide some initial climatic parameterizations by which existing cloud analysis models could be judged.

The snow/cloud discrimination sensor described here was intended only as an experiment. Actual testing of the data in an automated system such as the model mentioned above cannot be performed in an operational sense. Because of economic

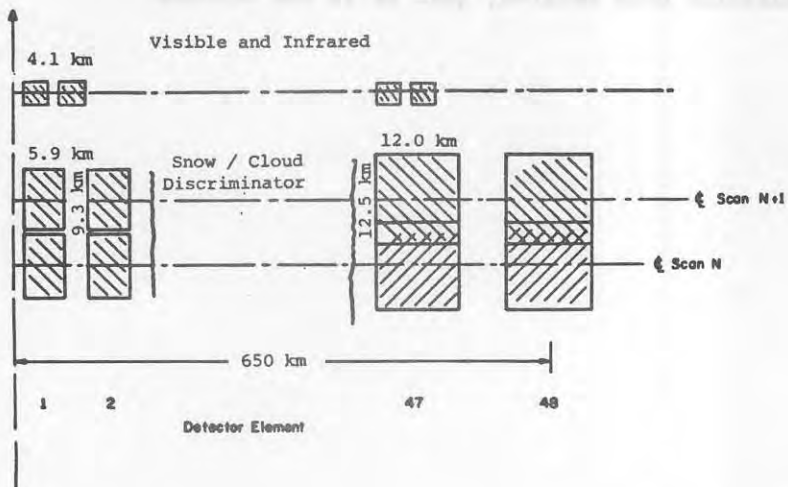


Figure 4

Snow/cloud discriminator vs. visible and infrared footprints (Kimball, 1979).

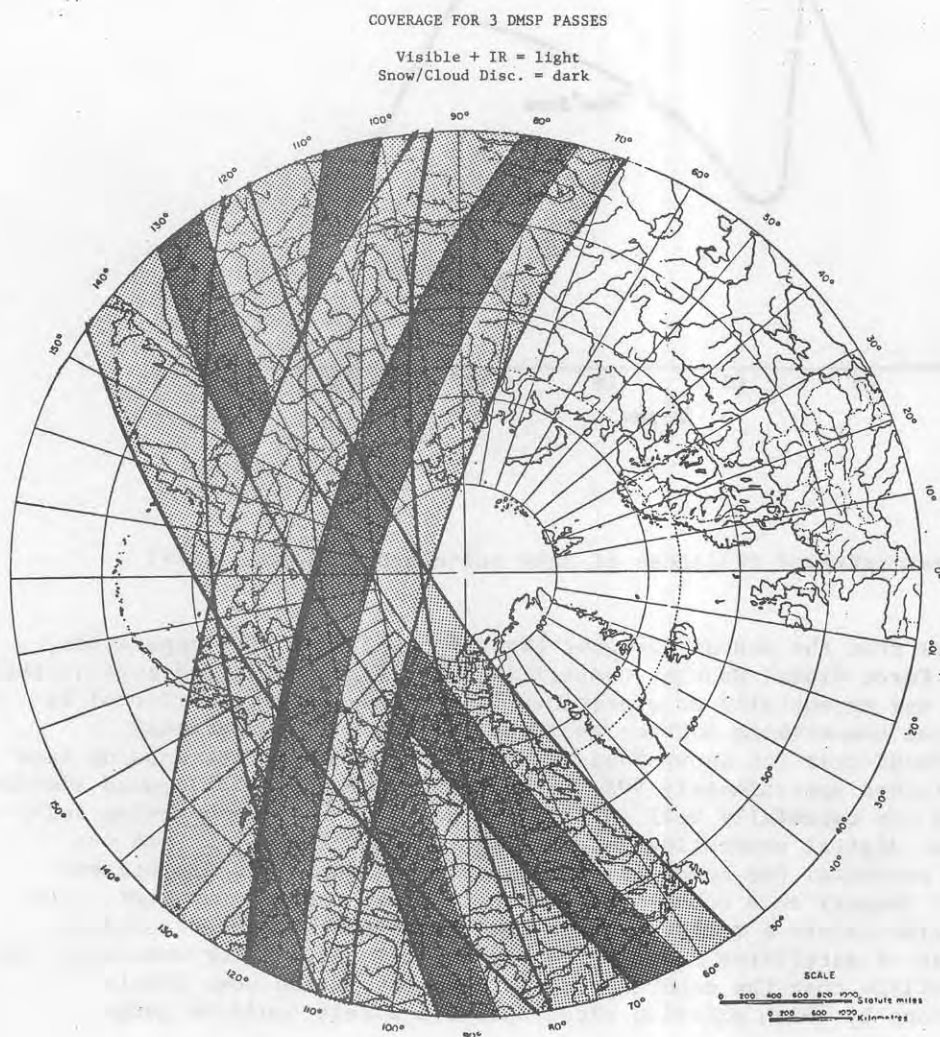


Figure 5

3 DMSP passes showing swath width for conventional vs. experimental data.



constraints on the experiment, design parameters of the snow/cloud discriminator were inferior to the conventional visible and infrared sensors. The most notable differences are reduced resolution and total area of coverage of the snow/cloud discriminator data. The 48 detector elements comprising one scan by the experimental sensor were not designed to compensate for projection on to a spherical earth, so footprint size increases linearly from 5.9 km by 9.3 km at subtrack to 12.0 km by 12.5 km at the scan edge in contrast to a constant 4.1 km resolution in the visible and infrared channels (figure 4, Kimball, 1979). In terms of total coverage, the snow/cloud discriminator swath is only one fourth the width of the conventional channel swaths so selection of a scene for analysis cannot be made arbitrarily (figure 5). Loss of solar illumination at high latitudes on the snow/cloud discriminator is compensated for by 16 gain settings compared with 64 on the visual and infrared data.

#### DATA ANALYSIS

The snow/cloud discriminator data for the project were obtained from the AFGWC, for the period 15 July 1979 through 30 December 1979, the life duration of the sensor. To correct the raw data for gain state changes and sun angle, the following equation was used (A.Kimball, personal communication, 1981):

$$\text{Radiance} = \frac{x}{63} \cdot K \cdot \frac{1}{GS} \cdot \frac{1}{SSE}$$

where  $x$  = the raw value in dB

$$K = \frac{5.23 \times 10^{-4} \text{ w cm}^{-2} \text{ sr}^{-1} \text{ inband radiance from a subsolar scene of 1.0 albedo}}{9.92 \times 10^{-4} \text{ w cm}^{-2} \text{ sr}^{-1} \text{ inband radiance from a subsolar scene cloud of .53 albedo}}$$

GS = gain step value times 2.4 dB (16 steps from 0 through 15)

SSE = scene solar elevation which is approximately equal to  $E + \theta \cos Az$

where  $E$  = solar elevation  
 $\cos Az$  = solar zenith angle

$$\theta = \sin^{-1} \left( \frac{R_{th}}{R} \sin \phi \right) - \phi$$

where  $R$  = radius of the earth  
 $h$  = altitude of the satellite  
 $\phi$  = nadir to line of sight

This calculation provides actual radiance values. To facilitate comparison between the snow/cloud discriminator and standard DMSP visual and infrared images the radiance values were assigned arbitrary gray shades on a linear scale (a total of 36 gray shades were used). According to this scheme, typical gray shades for various surface and cloud types are listed in Table 1. Note that land values cover a range of gray shades, often overlapping cloud values. This problem necessitates site-specific interpretation and use of visible imagery to distinguish between clouds and land on the snow/cloud discrimination data.

Two case studies were chosen for detailed analysis. Selection of cases was strongly dependent on the quality of data, inclusion of relevant snow and cloud information, and coincident coverage between snow/cloud discriminator and conventional visible and infrared data. The cases chosen are the Persian Gulf for 2 December 1979 and the Central Russian Uplands for 3 November 1979.

The Persian Gulf region represents a case with snow cover in the Zagros Mountains. This can be seen in the northeast corner of the visual DMSP imagery, figure 6a. This is a situation when snow cover could be misinterpreted as cloud to the

Table 1

Gray shades for various surface and cloud types

Gray shades	surface and cloud types
DARKEST	water (lakes, sea, etc.)
↑	snow
↕	land
↓	ice clouds
LIGHTEST	water clouds
	arid land

untrained eye or where mountain clouds and snow cover might be simultaneously present. The experimental data, figure 6b, indicates snow because of its dark shading, an example of the black snow effect in the near infrared. In contrast, the lightly shaded area over the Persian Gulf is indicative of cloud. Note that both of these areas have similar signals on the visual imagery. The infrared imagery, figure 6c, also helps distinguish snow from cloud areas in some cases because of the higher brightness temperatures of middle and high cloud types, snowcover usually has similar brightness temperatures to low cloud. Thus, the most reliable decisions can be made from the combined use of visual, infrared and near infrared bands.

The second region, the Central Russian Uplands, is a more complex case. A large band of snow can be identified on the visual imagery, figure 7a, by its sharp contrast from the Volga River. Note that the river does not stand out on the experimental data because both water and snow appear black in the near-infrared. This snow covered area is overlain in the upper portion of the image by clouds, a few of which (just west of the Volga River) are not apparent on the visual imagery. They can be identified in part on the infrared imagery since they are upper level clouds with relatively high brightness temperatures. They are even more obvious, however, on the snow/cloud discriminator data, figure 7b.

Also in the northwest area, the effect of forests on snow cover as seen from satellites is demonstrated. The forested area shown in figure 7d corresponds to a relatively dark area on the visual image suggesting a possibly snow free area. However, the snow/cloud discriminator signatures in this area are darker, indicating that the area is indeed snow covered. Although these signals are somewhat lighter than the snow covered steppes, they are still darker than the snow free areas to the south. From this example, it appears that the snow/cloud discriminator can determine whether forested regions are snow covered, a difficult task with visual imagery alone.

In the southern section of the image, a second area of clouds is of interest. In the visual image, figure 7a, two cloud areas appear in the lower corners. In the infrared image, figure 7c, the cloud in the southwest corner has a relatively dark signature, characteristic of low clouds. The cloud in the southeast corner appears bright indicating a high cloud. Its size is larger than seen in the visual image. This effect is typical of optically thin cirrus cloud. The snow/cloud discriminator data, figure 7c, illustrates the potential for distinction of cloud type (height) from the near-infrared imagery. In the near infrared band, high clouds (composed of ice crystals) have reflectance values intermediate between liquid water clouds (e.g. stratus, cumulus) and snow (Valovcin, 1978).

#### CONCLUSION

The snow/cloud discriminator made identification of features more certain than with just visual or infrared data. It is clear that the most reliable decisions are made using all three spectral bands in the interpretation. It is also apparent that the snow/cloud discriminator results alone would not provide sufficient information to make reliable interpretations in most cases.

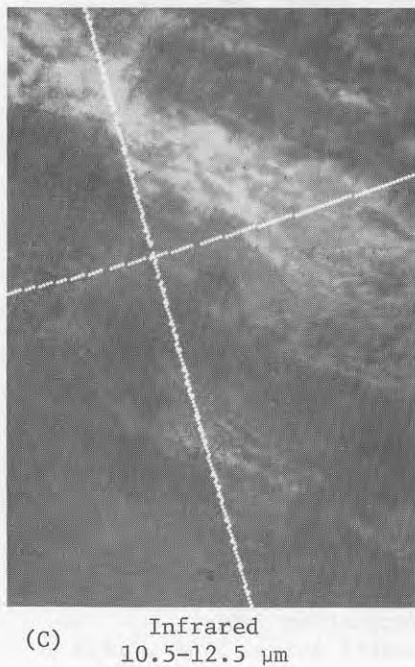
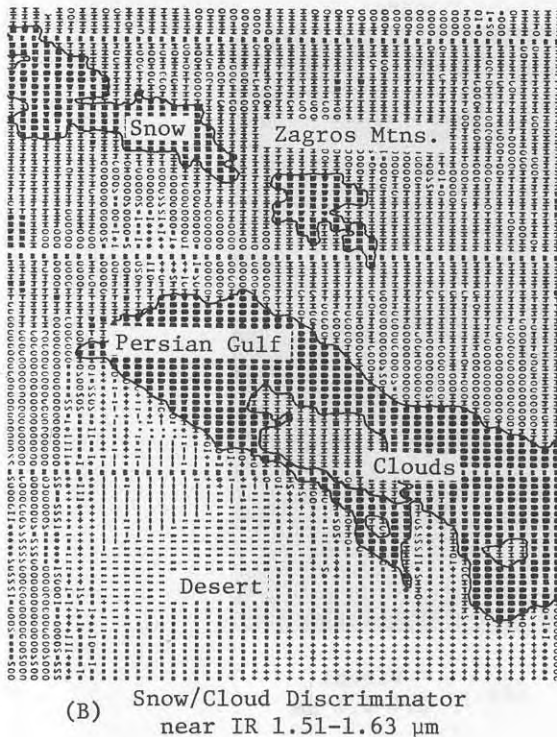
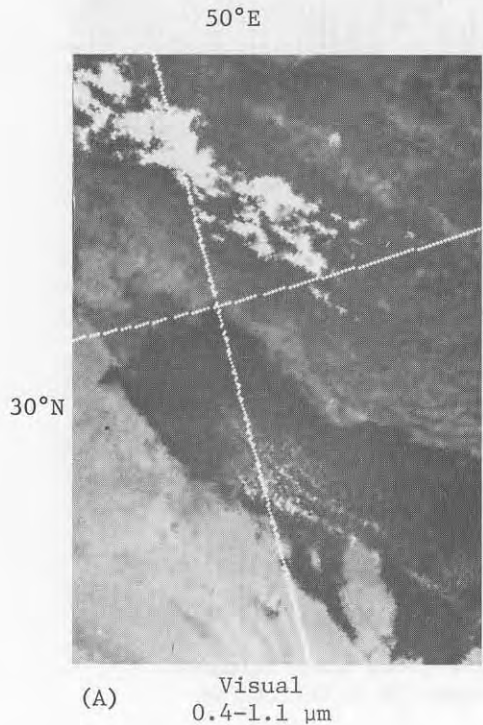


Figure 6. Persian Gulf study area for 2 December 1979  
in visual, near-infrared, and infrared spectral bands



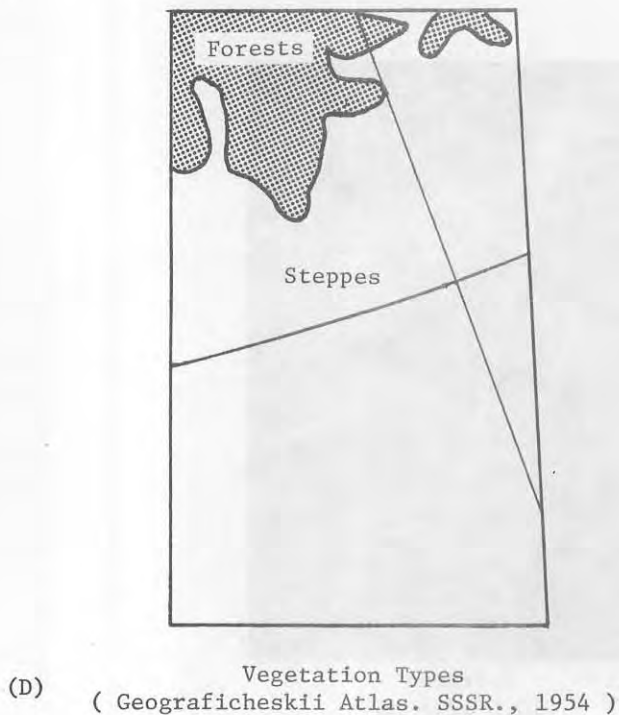
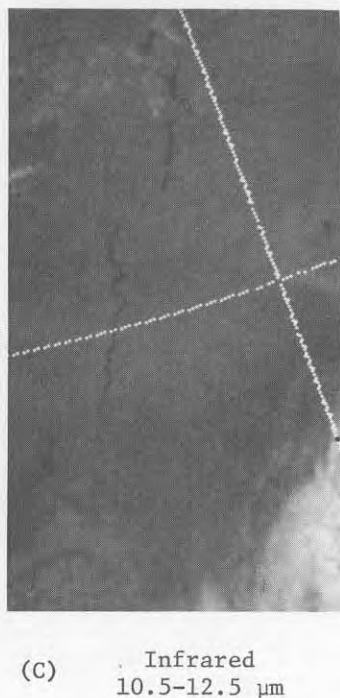
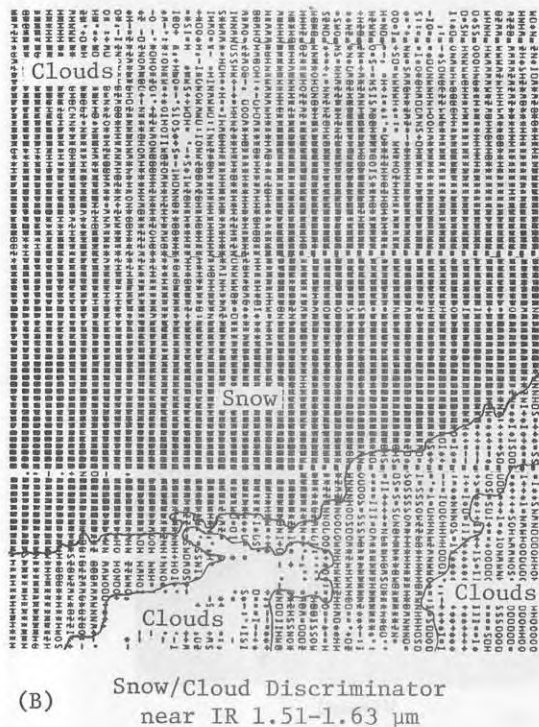
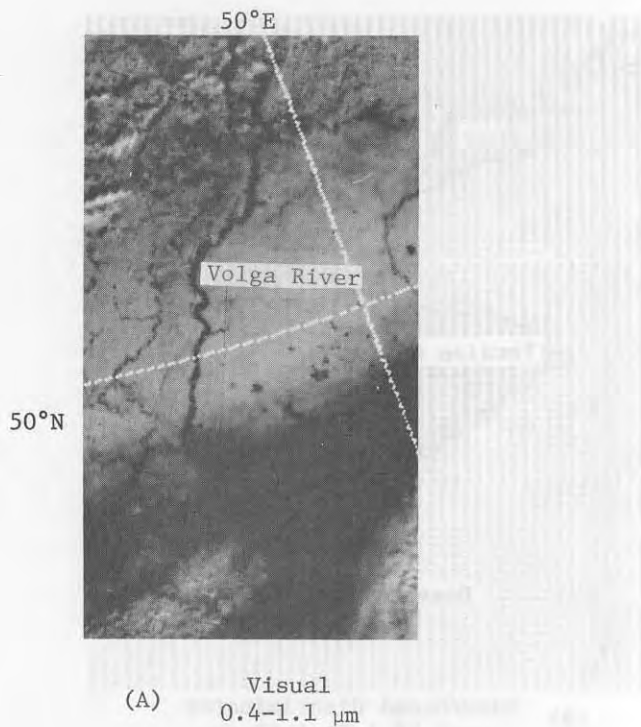


Figure 7. Central Russian Uplands study area for 3 November 1979 in visual, near-infrared, and infrared spectral bands and related vegetation types.



From our initial study of two cases, it appears that there is great potential for an operational sensor in the near-infrared to supplement conventional imagery for improving interpretation of snow and cloud scenery from satellite photos. However, analyses of the experimental data in its present form are limited by the following problems:

- poor and inconsistent resolution
- limited spatial coverage
- limited number of gain control step adjustments
- limited temporal coverage
- highly variable snow-free land values
- limited latitudinally, seasonally, and diurnally by solar illumination conditions

In summary, similarity of specifications between the experimental and conventional data are the major hindrance to a detailed comparison. The problem of highly variable land values will be overcome as our knowledge of the reflectance properties of various surface types in the near-infrared increases. The near-infrared data will always be limited by solar illumination, however, we feel this is not a major drawback since all short-wave data have similar limitations.

Ideally, data from a snow/cloud discrimination sensor could be used in a computer model with conventional visible band (0.4-1.1  $\mu\text{m}$ ) data to provide automated separation of snow vs cloud scenes. It has been suggested that improved snow/cloud discrimination would significantly improve output from operational models such as the Air Force Automated Cloud Analysis (Kimball 1981).

Further use of the experimental data in order to improve our understanding of cloud-climate interaction for climate models would not be practical. We strongly recommend, however, that future satellite systems incorporate operationally designed near-infrared sensors in the 1.51-1.63  $\mu\text{m}$  range. Such a system would make significant contributions to a variety of disciplines and applications.

#### ACKNOWLEDGMENTS

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