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The objective of this study is to determine the effect of clouds on clear Landsat pixels that are adjacent to cloudy pixels. A partly cloudy scene over a well-defined ocean background was analyzed and the effect of clouds on the clear pixels as a function of cloud amount was determined. The amount of scattering that occurs is proportional to the amount of cloud edges in the vicinity, which is proportional to cloud amount. For each non-cloudy pixel, the cloud fraction was computed in a 7x7 box using a simple threshold technique, and the average brightness in that box was compared with the brightness you would expect to measure if there was no scattering taking place:

$$\text{Obs} = (1-n)\text{Ocean} + (n)\text{Cloud}$$

where Obs = observed Landsat grayshade, Ocean = clear-column ocean brightness value, Cloud = grayshade value of a Landsat pixel that is completely filled with a cumulus cloud, and n is the cloud amount in the 7x7 box. Any difference from this behavior is due to scattering.

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The Adjacency Effect of Clouds in LANDSAT MSS Data

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1. INTRODUCTION

The objective of this study is to determine the effect of clouds on clear LANDSAT MSS pixels that are adjacent to cloudy pixels. Water droplet clouds are efficient scatterers of visible and near-infrared solar radiation. Scattering of radiation by clouds within a particular field of view can affect nearby pixels that do not contain clouds. A partly cloudy scene over a well-defined, uniformly dark ocean background was analyzed and the effect of clouds on the adjacent clear pixels was determined as a function of cloud amount.

2. ANALYSIS METHOD

Landsat MSS data from a scene in the Bering Sea on 26 August 1980 was chosen for this analysis. The scene contains a group of small-scale cumulus clouds. Solar elevation is sufficiently high for good scene illumination, and the uniformly dark Bering Sea serves as a useful, well-behaved background over which to investigate the attributes of scattering by cloud edges into adjacent fields of view. The over-water background also simplifies the complex effects of cloud shadows. Cloud imagery for the selected scene is shown in Figure 1.

The magnitude of scattering by clouds, called the "cloud adjacency effect," is proportional to the amount of cloud surface area exposed to incident solar radiation in the vicinity of a field of view. Although not precise, cloud fraction is used in this study to specify the amount of cloud surface area near a given pixel. Cloud fraction is determined simultaneously for each MSS image band 4-7 by applying a threshold brightness below which no clouds appear to be present in the image. MSS Band 7 data are useful for determining this threshold since scattering by the atmosphere and by clouds is minimal at the longer near-infrared wavelengths. The cloud mask was generated for each pixel and for each MSS band in the scene by flagging all pixels with a band 7 grayshade greater than 15. Figure 2 contains this cloud mask for the images in Figure 1.

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Cloud fraction "in the vicinity" of each pixel is then computed by counting the number of cloudy pixels in the surrounding 7x7 box, and dividing through by the total number of pixels. Cloud fraction is used as a measure of the amount of cloud surface area that is exposed to incident solar radiance. Hence, fraction is a measure of the degree to which cloud scattering takes place.

If the cumulus clouds from one pixel have no effect on the upwelling radiance measured in an adjacent pixel, then the dependence of radiance on cloud fraction (cloud surface area) in a 7x7 box is linear, and would be described as

$$I_{OBS} = n I_{CLD} + (1-n) I_{CLR} = (I_{CLD} - I_{CLR}) n + I_{CLR} \quad (1)$$

where I_{OBS} , I_{CLD} , and I_{CLR} are the observed Landsat MSS radiances for a partly cloudy, completely cloud-filled, and cloud-free (water) pixel, respectively, and where n is cloud fraction ($0 \leq n \leq 1$). Any deviation from this dependence represents the effect of scattering into the field of view by cloud edges in adjacent pixels.

A plot of radiance (which for Landsat MSS bands 4-7 are linearly proportional to grayshade) as a function of cloud amount can be produced from the image data for each MSS band. For each pixel in the scene the local cloud fraction n is computed for the surrounding 7x7 box. Then the grayshade for that pixel is tabulated as a function of cloud fraction. Once completed for the entire image, the average grayshade for each cloud fraction is then computed and compared to the linear shape that is assumed by Eq. (1). This plot is shown in Figure 3.

3. RESULTS AND SUMMARY REMARKS

In Figure 3 it is seen that the cloud adjacency effect is both nonlinear and wavelength-dependent for MSS bands 4 and 5. For bands 6 and 7 the effect is essentially non-existent; that is, radiance is linear with cloud fraction. MSS bands at the lower wavelengths are most strongly affected by scattering. Also, the adjacency effect is strongest for $n \approx 0.7$. The vertical difference between the dotted straight line in Figure 3 [the linear assumption as defined by Eq. (1)] and the curves for bands 4 and 5 quantify the effect of cloud scattering into non-cloudy, adjacent fields of view.

Curves such as Figure 3 may prove useful in removing the scattering effects of clouds from Landsat data in order to more accurately retrieve the reflectance attributes, such as vegetation indices, of cloud-free surfaces. Also, if cloud fraction is the retrieval parameter of interest, adjacency effects when not properly accounted for generally lead to an overestimation of cloud fraction.

Future work will include reconstructing the Bering Sea scene using the results plotted in Figure 3 to determine whether the corrected cloud-free pixels have a uniform dark appearance. More challenging studies include analysis of scenes with non-water backgrounds where shadowing effects significantly complicate the satellite-measured reflectances.

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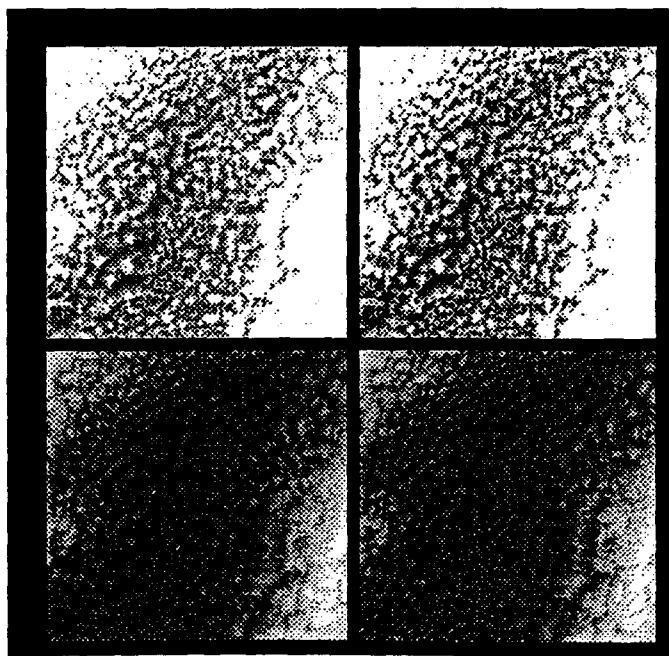


Figure 1. Landsat MSS Band 4 (0.5-0.6 μm , Upper Left), Band 5 (0.6-0.7 μm , Upper Right), Band 6 (0.7-0.8 μm , Lower Left), and Band 7 (0.8-1.1 μm , Lower Right) Images for the Bering Sea, 26 August 1980.

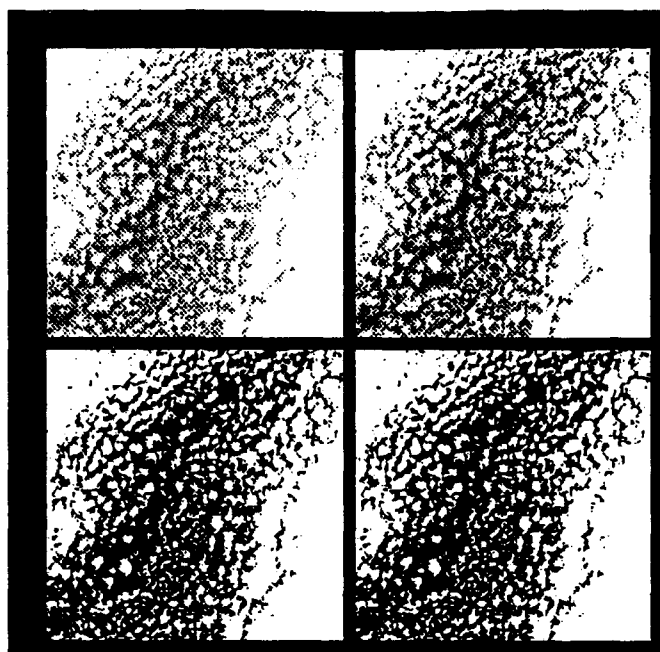


Figure 2. Landsat MSS Images of Figure 1, with the Cloud Mask Applied. Bright White Pixels are Cloud-Filled; all Others are Cloud-Free.

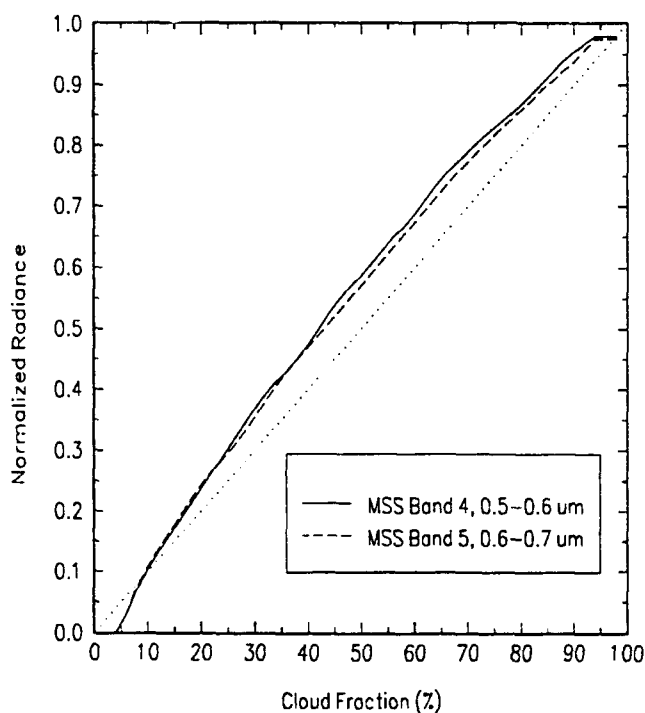


Figure 3. Landsat MSS Bands 4 and 5 Normalized Radiances as a Function of Cloud Fraction. The Dotted Straight Line Denotes the Non-Scattering Condition Specified by Eq. (1).

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