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VISIBLE AND INFRARED RADIATIVE RELATIONSHIPS AS MEASURED BY SATELLITE AND LIDAR

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1. INTRODUCTION

The impact of cirrus clouds on the heat balance of the earth is dependent on their reflectivity of solar radiation and their absorptivity of terrestrial radiation. These clouds can either contribute to radiative warming or cooling depending on the ratio of their visible reflectance to their infrared absorption. Any prediction of cloud cover changes that accompany climate change, will have to know whether the visible/IR radiative characteristics of the clouds will also change. Few measurements of cirrus have been made where data from both the visible and IR were collected simultaneously. Most cloud studies have used only one portion of the spectrum.

The best studies of the visible and IR radiative properties of ice clouds have been Platt (1979) using a vertically pointing IR radiometer next to a visible lidar and Minnis et al. (1990) which combined satellite and lidar data. Platt (1979) studied several cases of cirrus clouds and found a ratio of the visible/IR optical depths of 2.0:1. Minnis et al. (1990) studied one case from the FIRE experiment and found the visible/IR ratio to be slightly higher, 2.1:1. Modelling of radiative properties of ice crystals suggest that the visible/IR ratio can vary from 1.8 to 4.0 (Minnis et al., 1993).

One of the largest problems for any cirrus cloud study is the large spatial variability of clouds. Vertically pointing lidars sample only the part of the cloud that drifted over them while satellites see the gradients in the horizontal field. Lidars have a vary narrow beam, < 1 m in width while satellite radiometers have field of views (FOV) of 1 to 20 km. For this study, we used a scanning lidar to make volume imagery of cirrus clouds similar to the satellite view of the clouds.

2. MEASUREMENT TECHNIQUE

To obtain the visible optical depths of cirrus, the High Spectral Resolution Lidar (HSRL) and the Volume Imaging Lidar (VIL) of the University of Wisconsin-Madison were used. The HSRL is a unique instrument that measures the backscatter of the lidar pulse by particulate matter separately from the backscatter of air molecules. A spectrally narrow pulse of 0.6 μ from a NadYg lidar is transmitted. The returning radiation scattered by air molecules will be spectrally doppler broadened while that from particles will not. Measurements of both the doppler broadened and non-broadened backscatter are made. The backscatter from air molecules allows a direct determination of the strength of the lidar pulse reaching each level of the cloud. Extinction and optical depth of the cloud can be determined without assumptions of the attenuation along the beam path. More precise measurements of the visible radiative quantities of the clouds can be made this way.

To understand radiative scattering in clouds, the large horizontal and vertical variations in cloud structure have to be measured. The HSRL lidar samples only a small portion of the cloud - a column about 30 centimeters wide. The GOES satellite IR sensors have a horizontal resolution of 10.8 km at Madison, WI. To account for FOV differences, the horizontal structure of the clouds were measured by the VIL.

The VIL produced visible backscatter images of the clouds by scanning across the wind. Time advection was used to construct a horizontal image of visible backscatter from the VIL data over a one hour period. The HSRL was used to calibrate the VIL signal into backscatter cross sections of particulates. The backscatter cross sections were related to extinction by a constant backscatter phase function determined from the HSRL data. This process produced a three dimensional image of visible extinction in the cirrus clouds over a one hour period.

The extinction volume image was then transformed to an image of optical depth in the same viewing geometry as the

GOES satellite. Optical depths were formed from the integral of extinction along the path in which the GOES scanner view this volume. The optical depth image was originally produced with a 1 km (satellite nadir) resolution. This image was then shifted to align with the satellite IR image to account for error in the satellite registration system. The lidar visible optical depth image then was averaged to an 8 km (satellite nadir) image for direct comparison to the satellite IR image. This gave coincident fields of views from both satellite and lidars in the same geometry with a horizontal resolution of 10.8 km per pixel.

IR optical depths were extracted from the GOES image using calculations of the IR transmittance of the clouds using the IR radiance of the cloud, the radiance of cloud free FOV's and radiances calculated from the temperature of the mean vertical level of the cloud. The VIL data were used to determine the cloud level. Rawinsonde observations were made at Madison at the same time as these data.

All data were taken in the vicinity of Madison, WI on 1 December, 1989. The VIL was located 24 km west of the HSRL. The VIL scanned both crosswind and nearly downwind over the HSRL. Data were taken from 19:35 UTC (13:35 Local) to 21:20 UTC (15:20 L). During this time a large mass of cirrus clouds moved in from the west-northwest with an approaching cold front. Madison, WI was under cloud free sky during the morning and proceeded to total overcast by the end of this period. Two lidar images were constructed from 1 hour records. More details on the data taken can be found in Ackerman et al. (1993).

3. RESULTS

An example of the structure of the clouds from the VIL is shown in Figure 1. A thick cloud mass from 6.8 to 9.0 km is apparent from 8 km south to 20 km north of the VIL. Other thin broken layers are apparent both north and south of the large mass. This is typical of the different forms of cirrus sampled on 1 Dec, 89. The first clouds to reach Madison were vertically thin and horizontally broken. A few dense lines with evidence of precipitating virga also were found in the VIL volume. Later thicker cirrus moved in with virga that spanned the 2.2 km shown in Fig. 1.

The satellite and VIL image was divided into regions of similar cloud characteristics. The VIL cross sections were used as the primary division tool. The GOES image had little detail in the IR. The lidar visible optical depth image at 1 km showed many line and sheet structures. Cloud thickness, the presence of multiple layers and the intensity of precipitating virga were used to segregate different cloud forms.

The visible/IR optical depths are shown in Fig. 2. Most of the data are near the 2:1 line shown in the image. These data loosely agree with theory and the other past measurements. However, the visible/IR optical depth ratio appears to increase for thicker precipitating cirrus. Clouds with dense precipitating virga have ratios below the 2:1 line (visible/IR > 2). Cloud areas of highest reflectivity had solid lidar returns over 2 km depth with occasional embedded layers of extremely high reflectivity. The horizontal variations in cloud reflectivity were seen in the IR satellite imagery but with far less detail than the lidar images. The lower resolution of the satellite IR sensor smoothed some of these variations. However, the lidar data show that visible reflectivity had wide range of values with large vertical and horizontal detail.

4. REFERENCES

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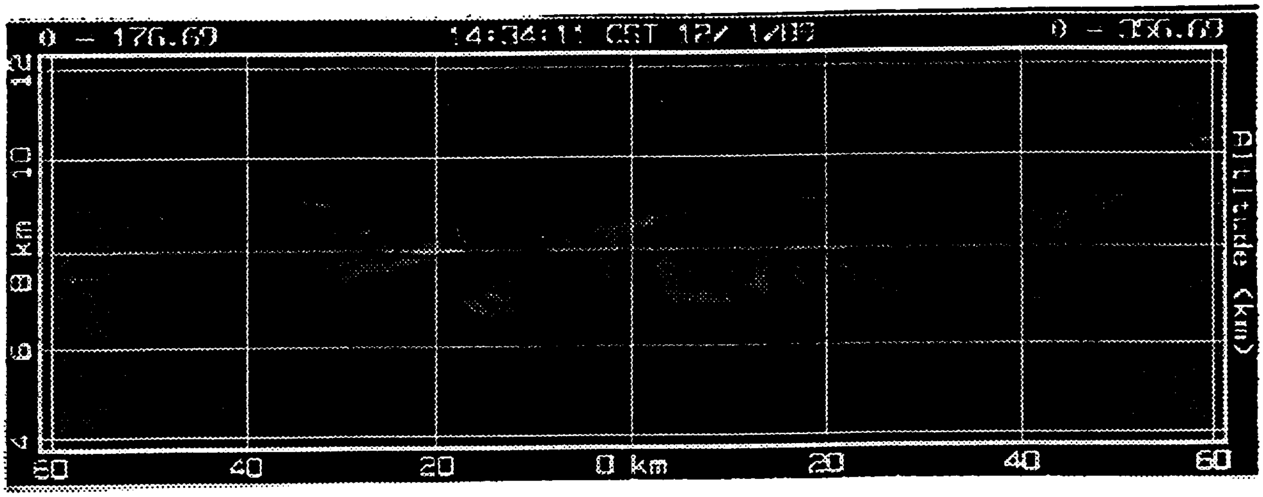

Figure 1: A Volume Imaging Lidar (VIL) cross wind section taken at 20:34 UTC (14:34 local). Scan directions were azimuths of 177° and 357°. Orientation is south to north.

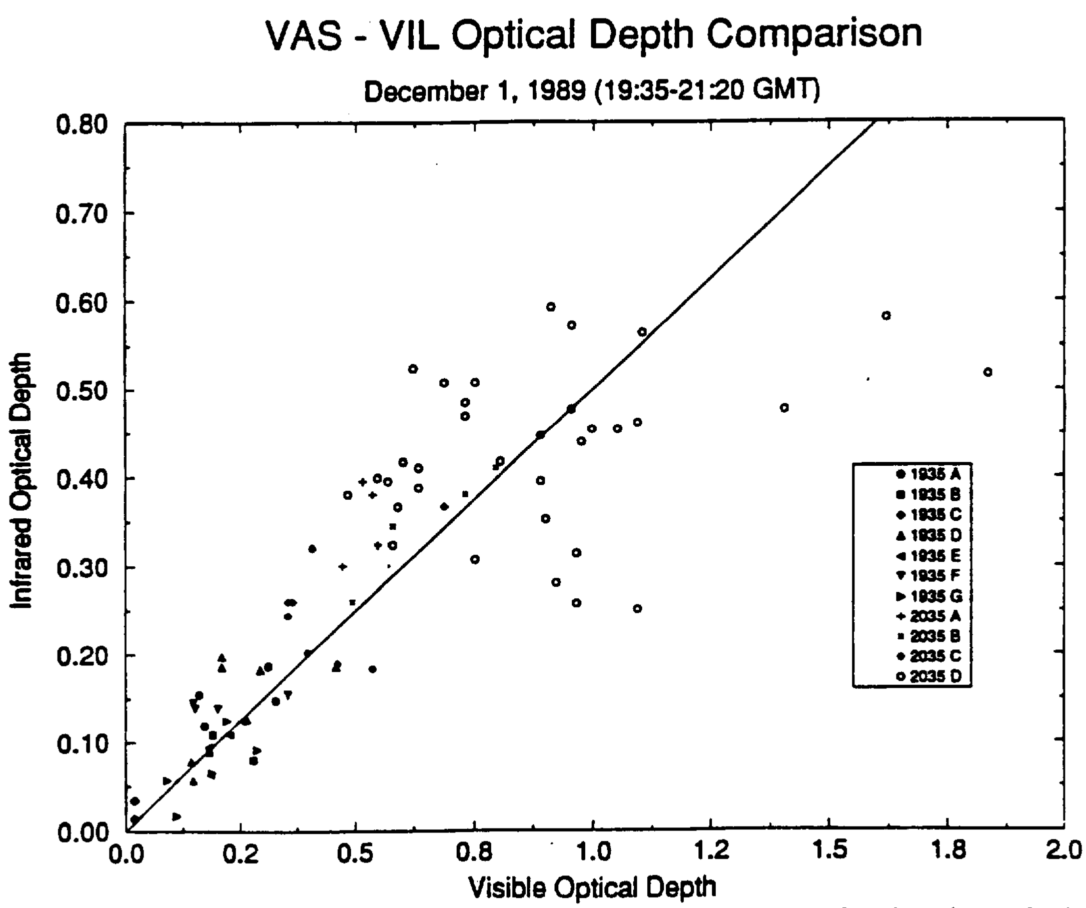

Figure 2: Scatter plot of the visible and IR optical depths of cirrus clouds using coincident lidar and satellite data.