Development of an Algorithm for Removing Thin Cirrus Scattering Effects in Landsat 8 OLI Data Using AVIRIS-Classic

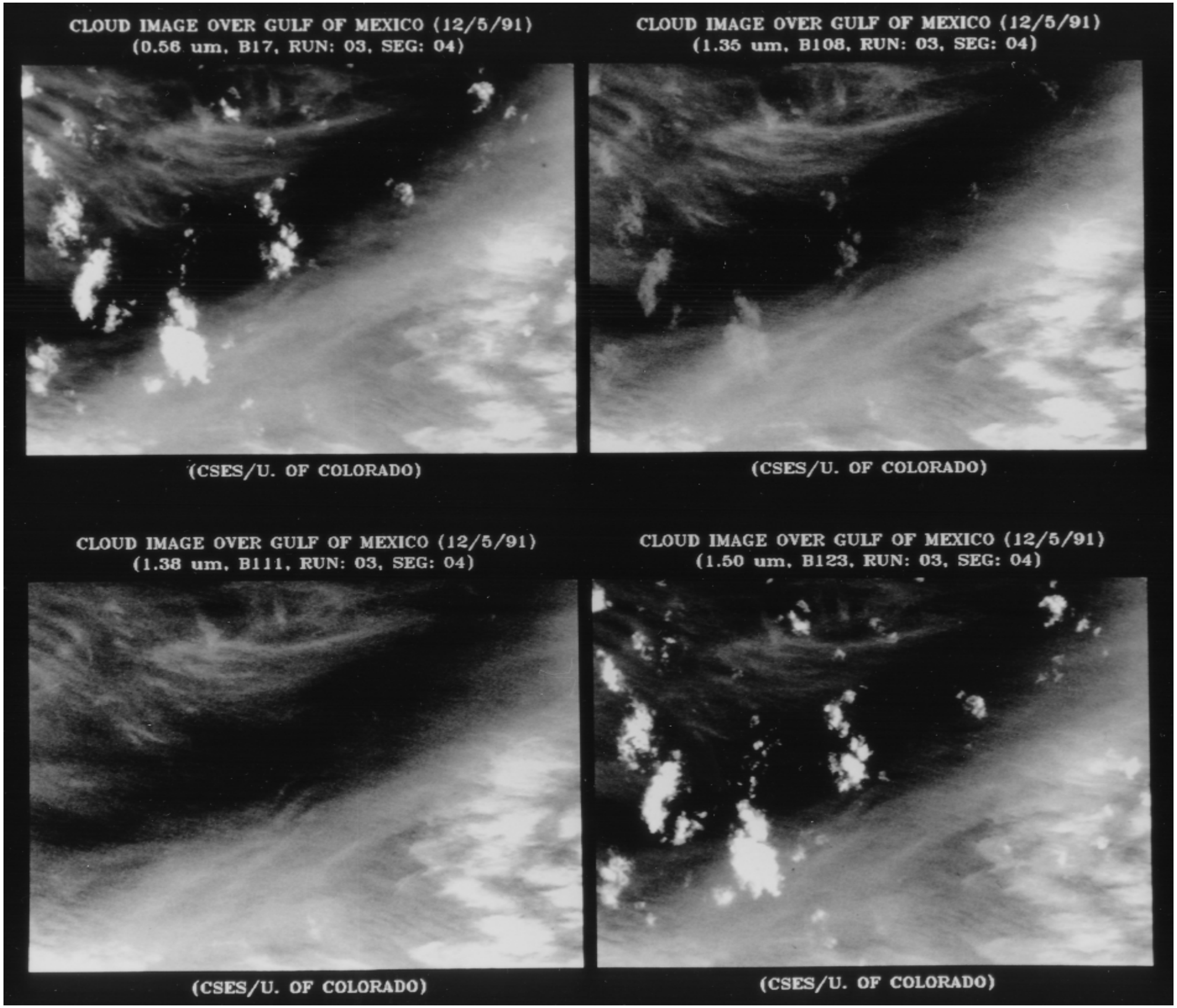
Bo-Cai Gao & Rong-Rong Li

Remote Sensing Division, Code 7230
Naval Research Laboratory, Washington, DC

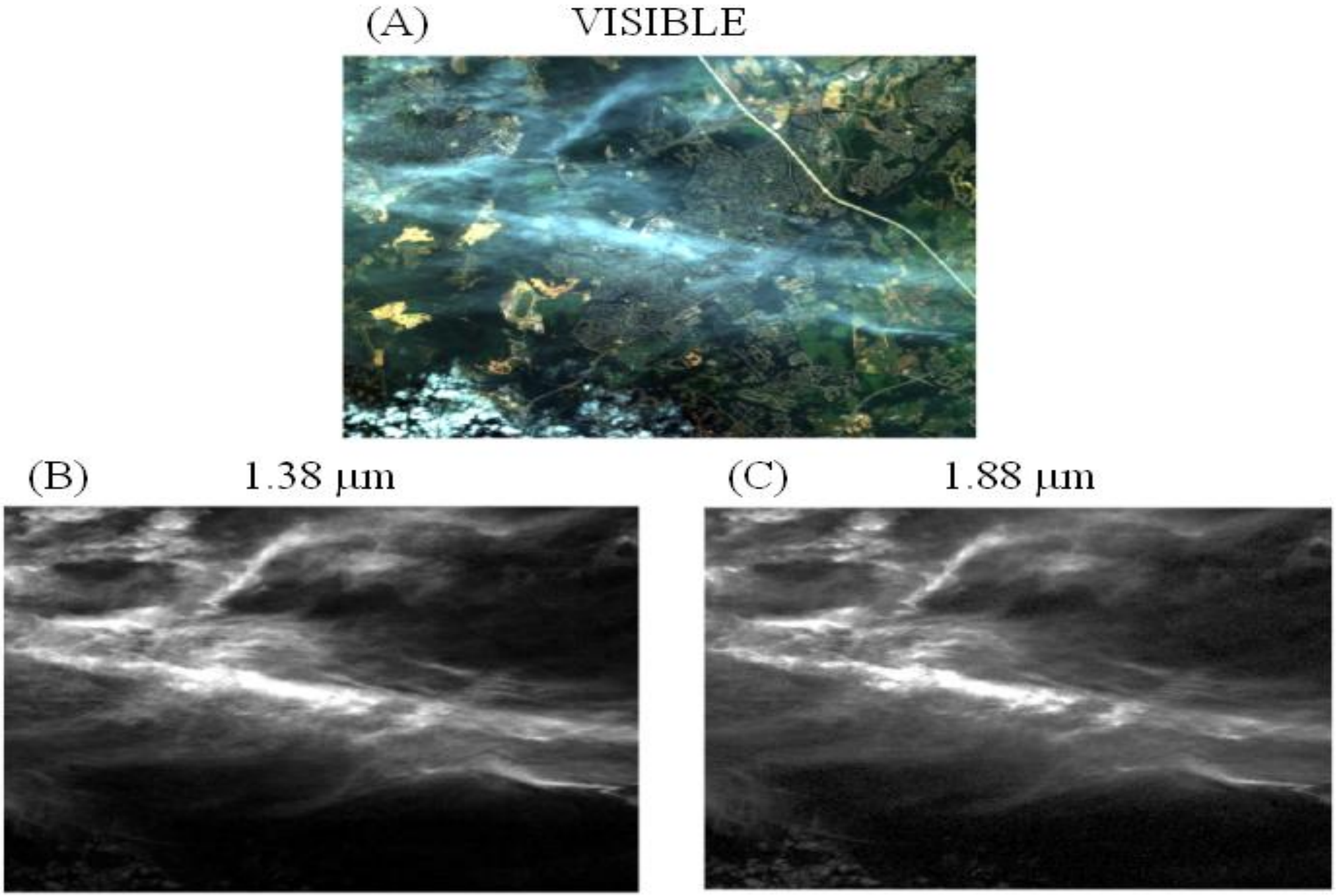
Introduction

- The Landsat 8 OLI instrument has a CIRRUS band centered near1.375 μm (Band 9). The specifications for this band were almost identical to our specifications for the MODIS cirrus detection channel (Band 26). Today, we will present:
- a brief history about cirrus detection using the 1.38-μm water vapor absorption band;
- examples on using the channel for improving remote sensing of atmospheric aerosols, land surfaces, and ocean color;
- development of a cirrus removal technique from Landsat 8 OLI data using AVIRIS-Classic data;
- sample results & a brief summary.

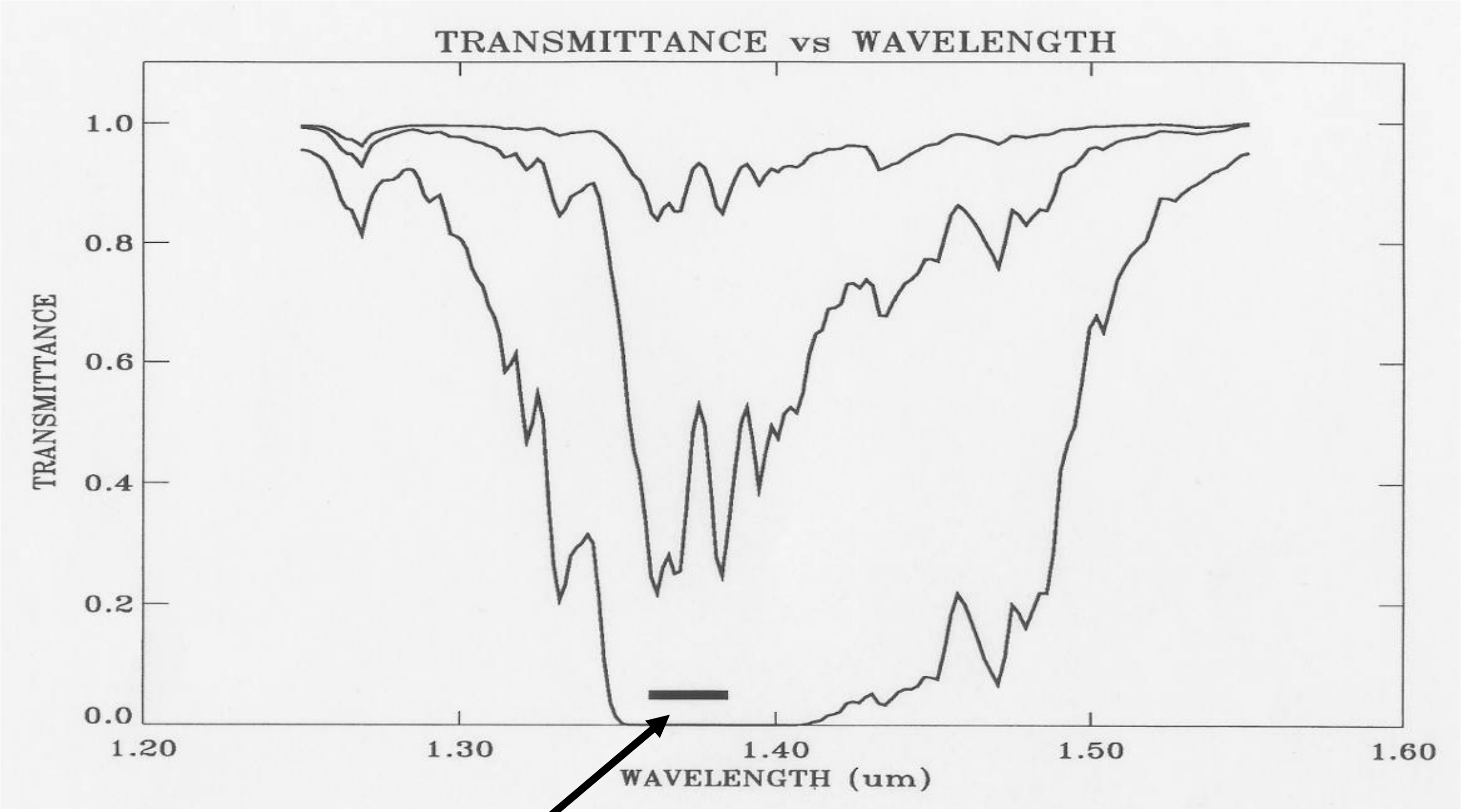
Sample AVIRIS Images from FIRE II Cirrus Experiment (12/5/1991)



Additional Examples of Cirrus Detection Using The High Spatial Resolution (20 m) AVIRIS Data



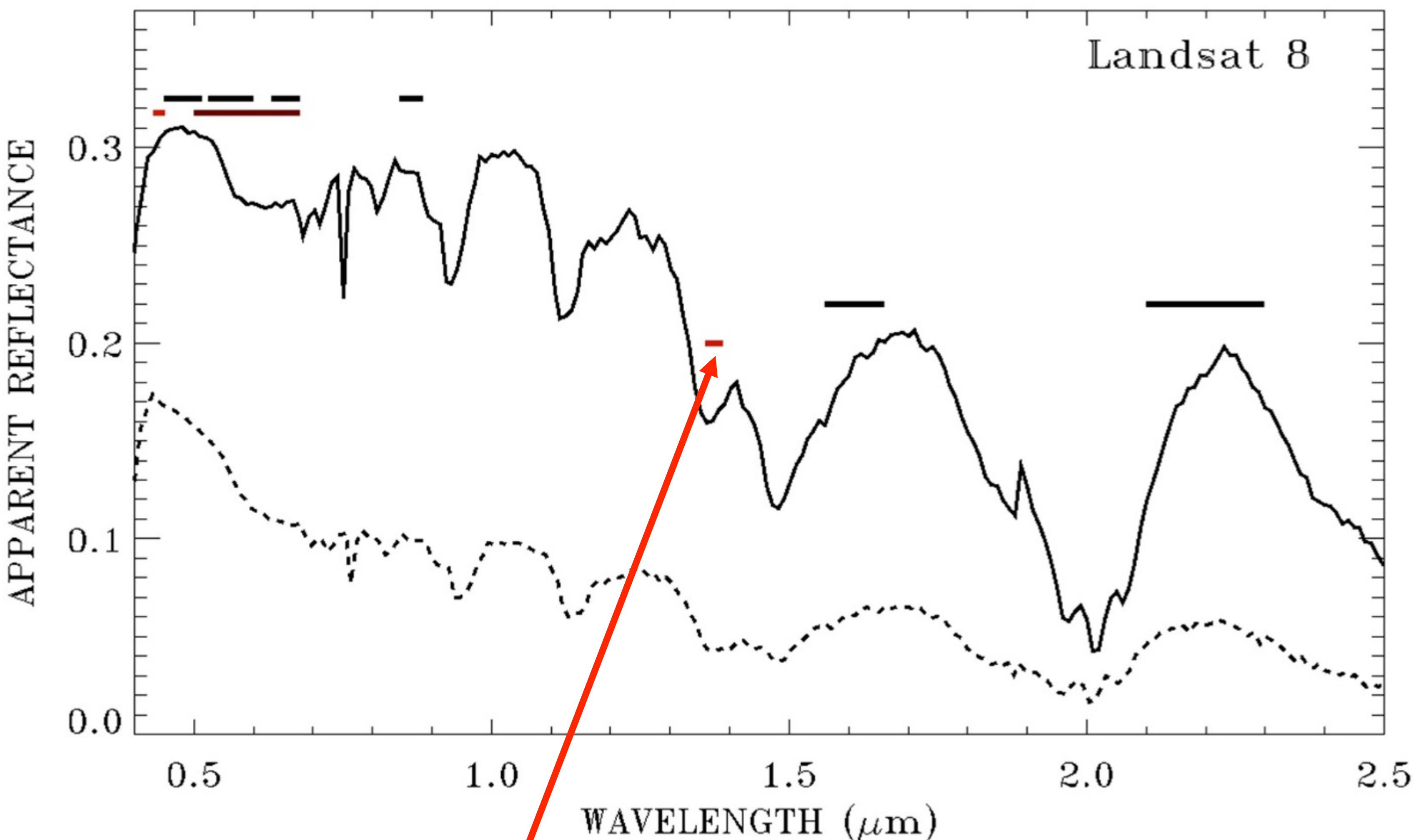
The selection of the MODIS 1.375-mm channel (30 nm width) for remote sensing of cirrus clouds



MODIS Channel 26

MTI, GLI, VIIRS, L8 OLI, Sentinel 2 MSI, PACE OCI have similar cirrus channels

Cirrus Spectral Properties & Landsat 8 OLI Bands



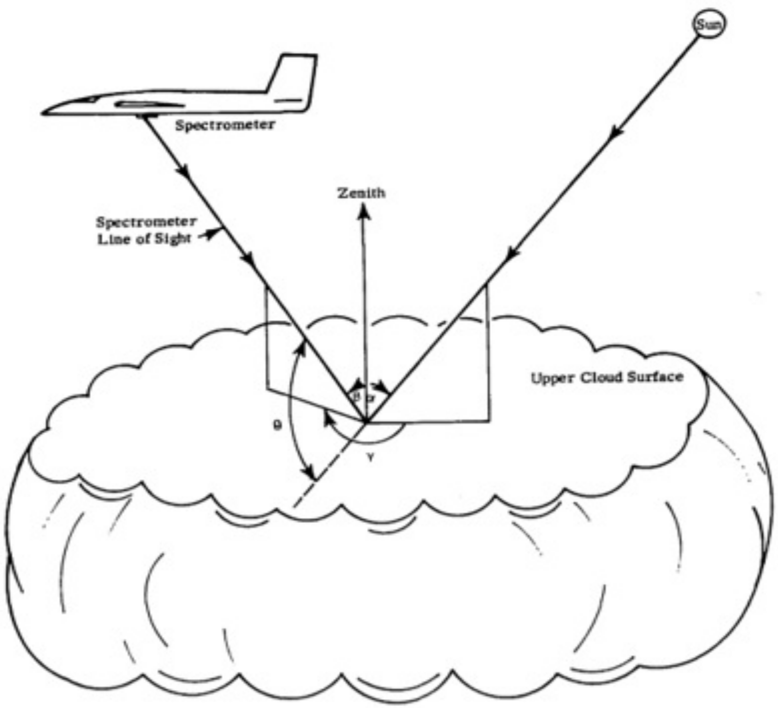
Landsat 8 OLI CIRRUS Band

Cloud Spectral Measurements in the 1960s

As reported in a 1966 Applied Optics Paper

Near Infrared Scattering by Sunlit Terrestrial Clouds

Henry H. Blau, Jr., Ronald P. Espinola, and Edward C. Reifenstein, III



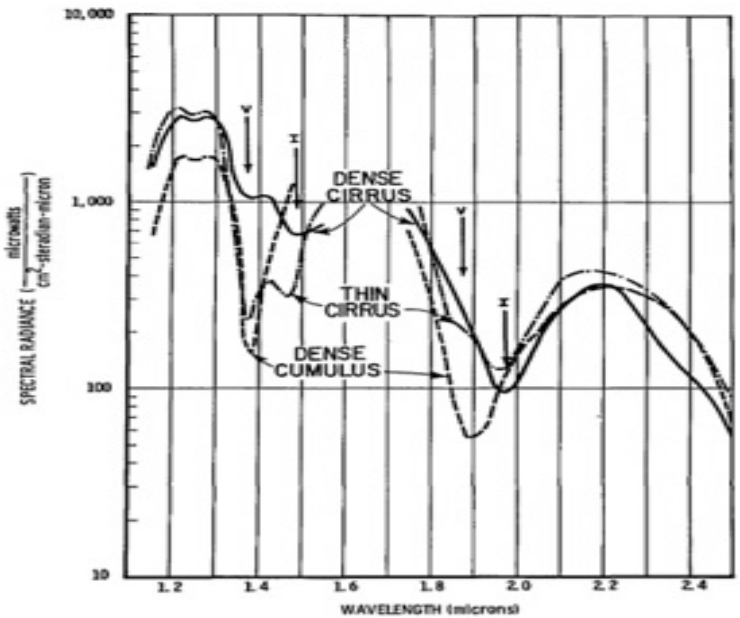
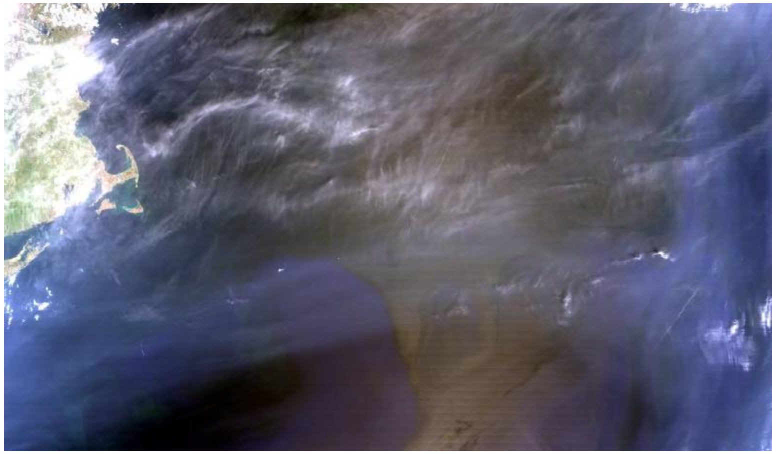


Fig. 11. Radiance spectra of cirrus over cumulus. Date: 14 October 1964. Loc: Central California. Cloud type: cumulus and cirrus. Cloud alt: 7.6 km–9.5 km. A/C alt: 11.2 km. β: 0°. α: 52°–44°. γ: 0°. θ: 128°–136°. S.S.W: 0.03/0.07 μ. Spectra: 1.

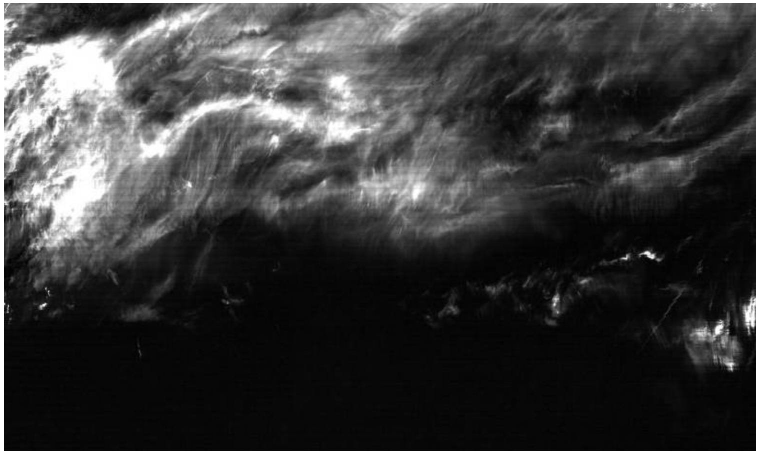
Since their instrument had no imaging capability, these researchers were unable to find out the utility of the 1.38- and 1.88-micron bands for cirrus detections.

An example of cirrus correction for better studies of lower level smoke layer

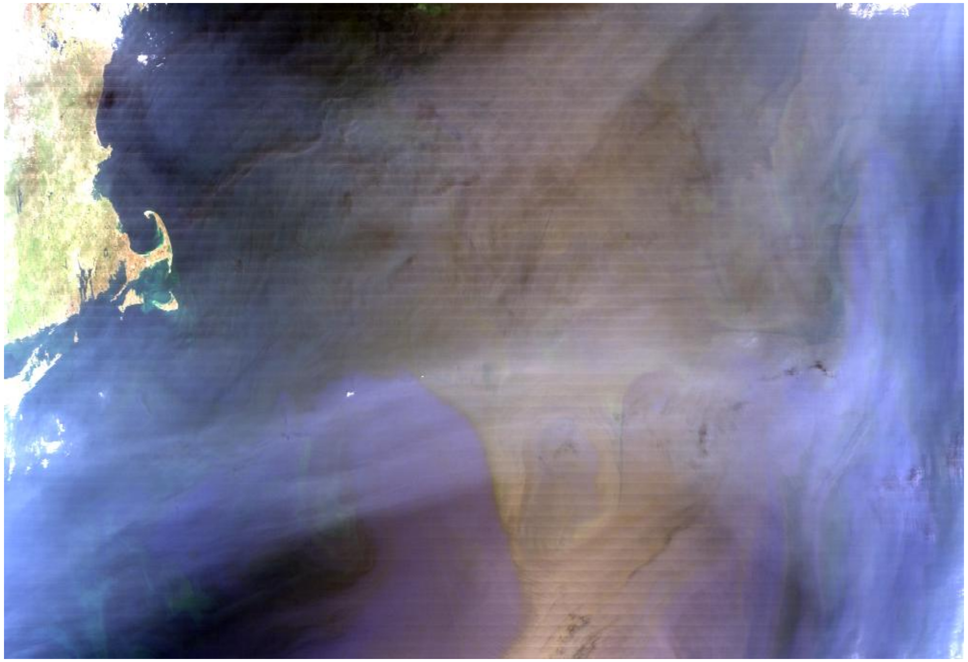
Visible Image



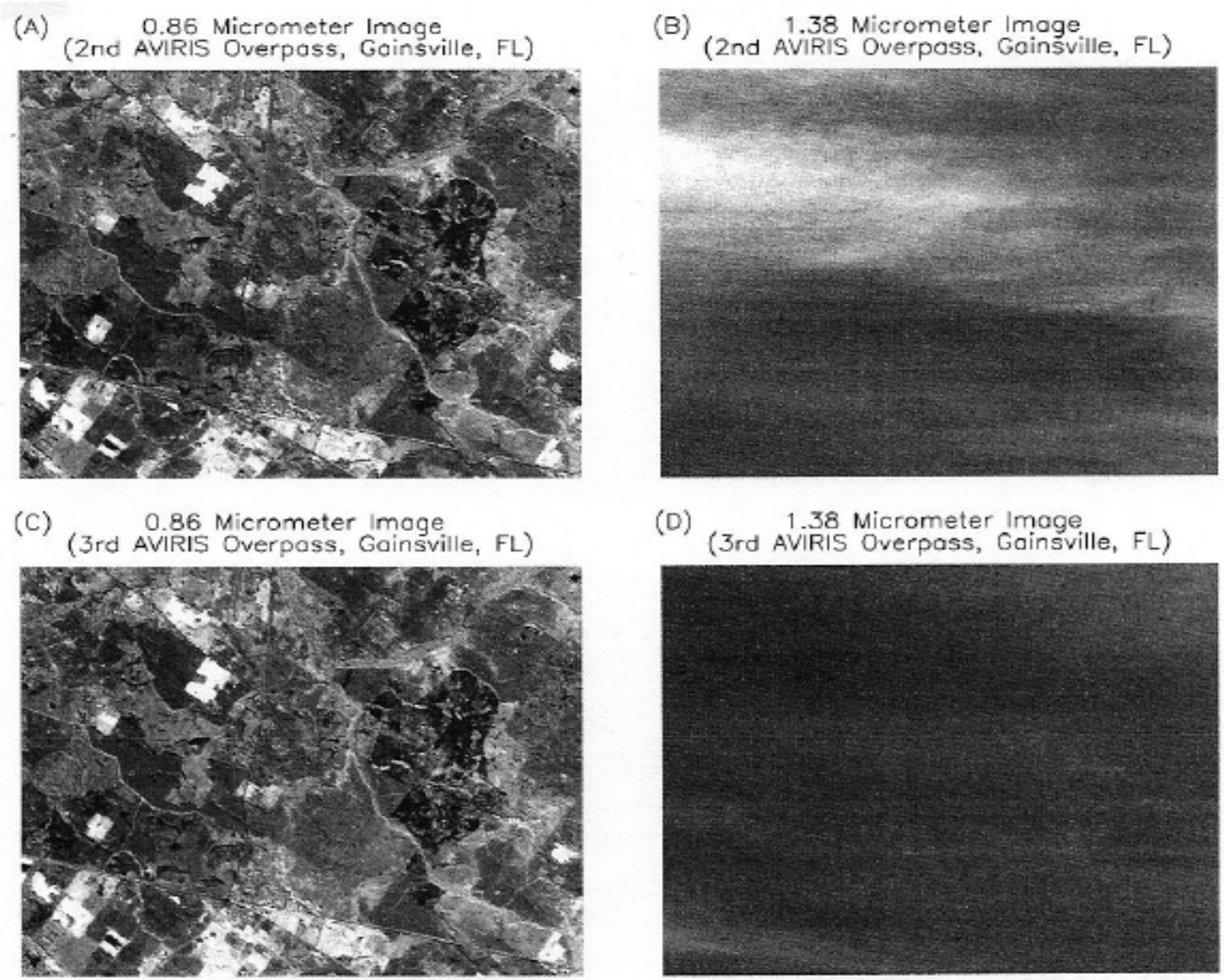
1.38-μm Image



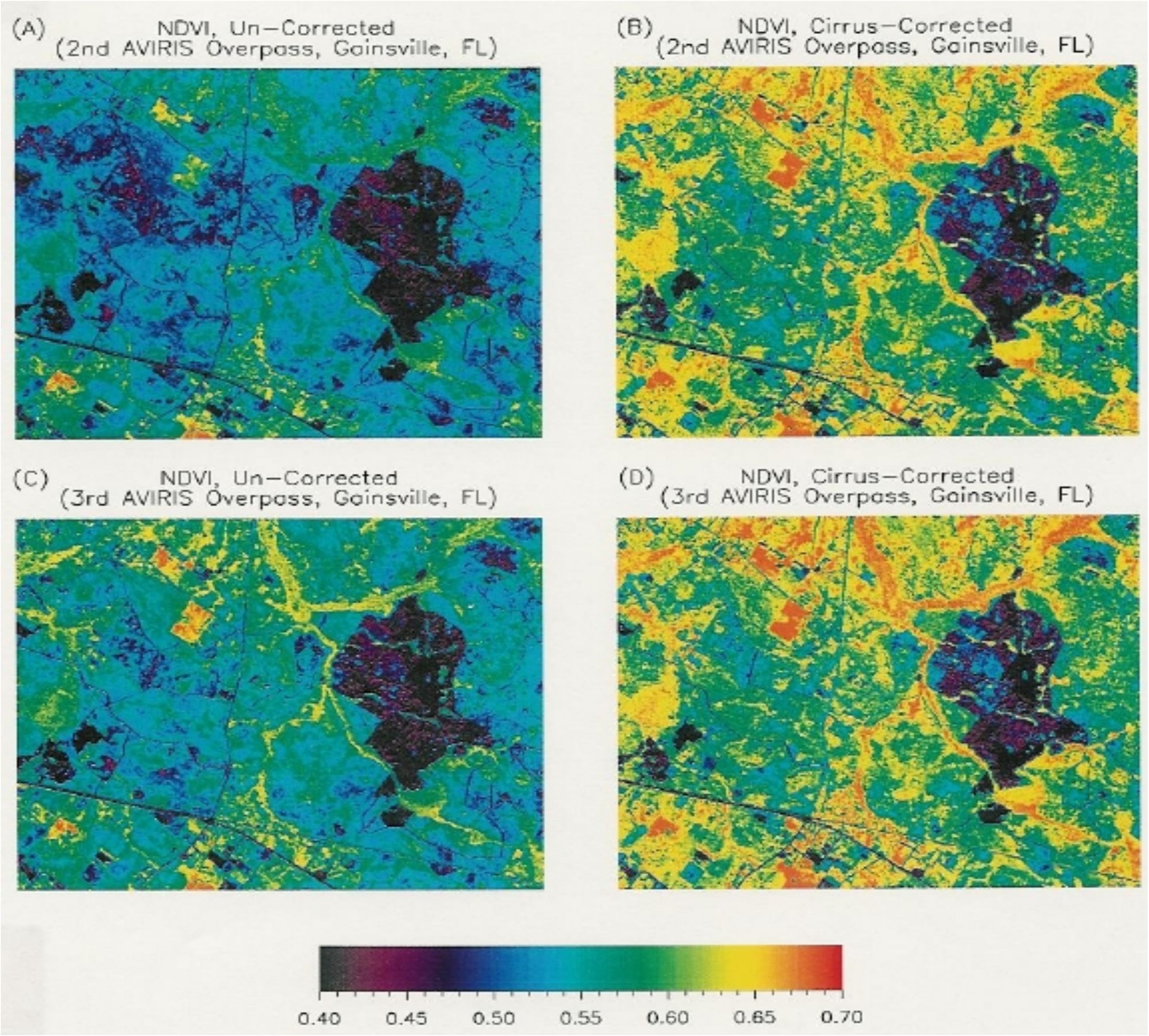
Cirrus−Corrected Image



An example of improving NDVI estimation by removing thin cirrus effects from AVIRIS data



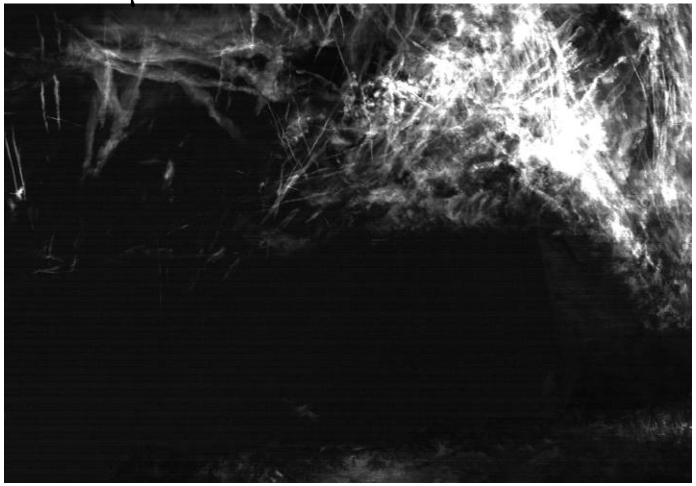
An example of improving NDVI estimation by removing thin cirrus effects from AVIRIS data (Continued)



An example of cirrus correction using MODIS data for improved remote sensing of land surface and ocean color

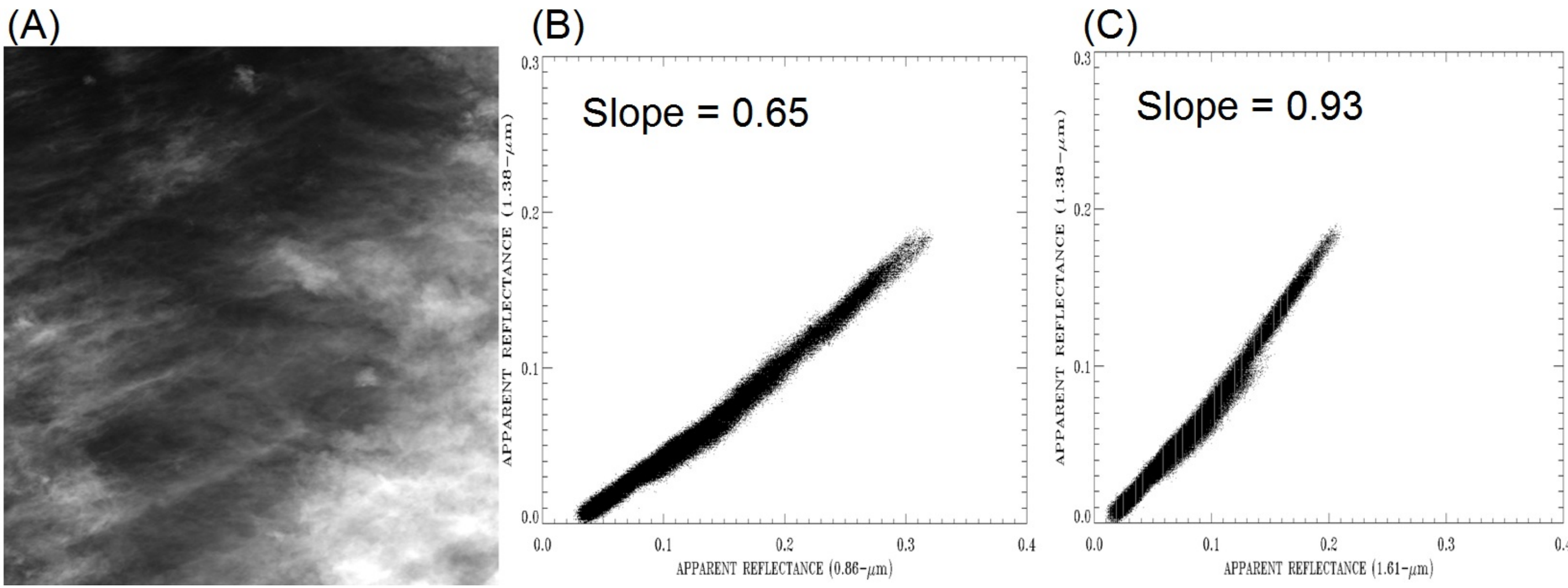
Visible Channels

1.375-μm Channel



Cirrus-Corrected Image

Illustration of linear relations between 1.38-micron band and NIR + SWIR band images using a set of AVIRIS data acquired over water surfaces



$$\rho^* = \frac{\pi L}{\mu_0 E_0}$$

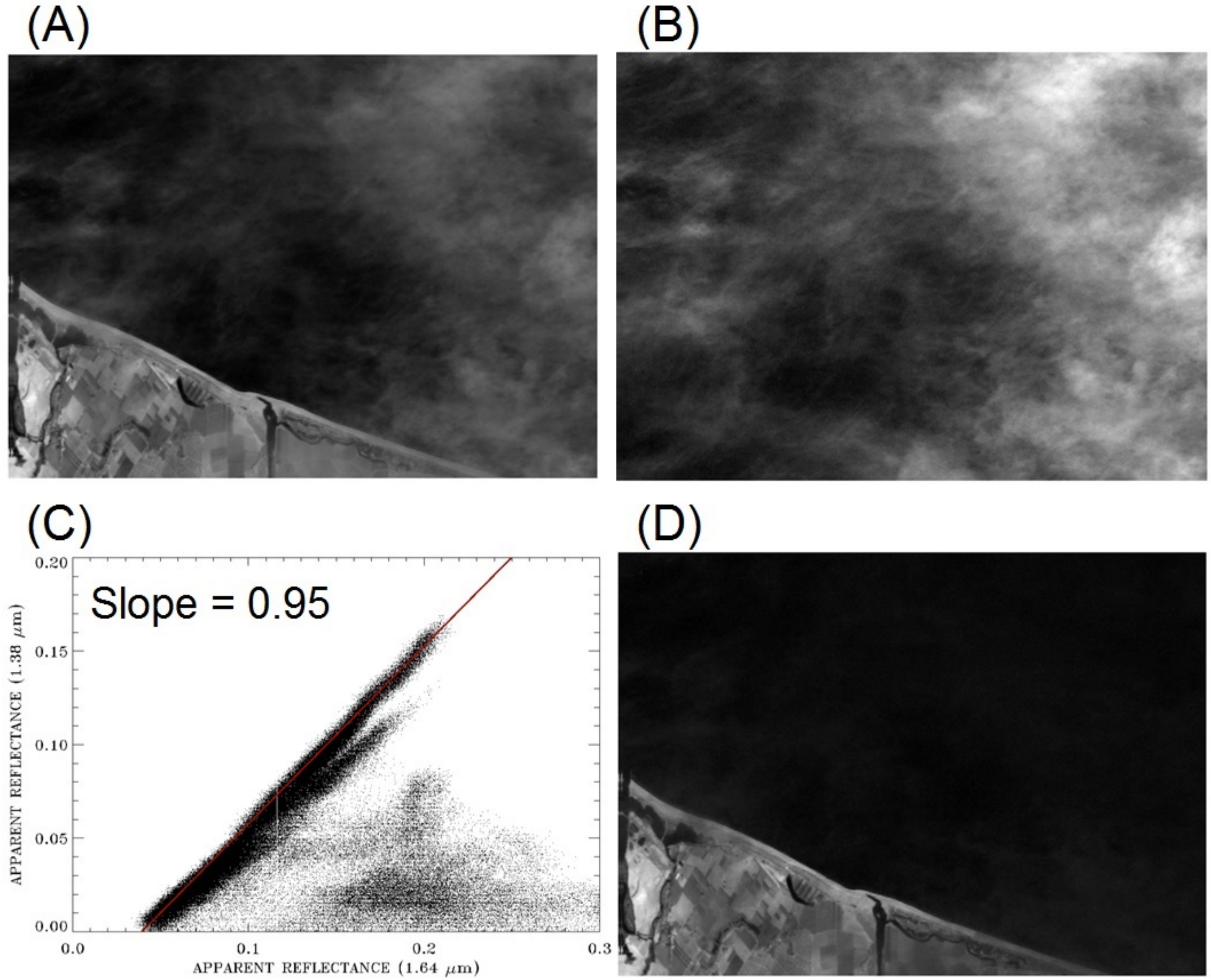
$$\rho^*(0.86\,\mu m) = \rho_C(0.86\,\mu m) + \rho_R(0.86\,\mu m)$$

$$\begin{aligned}\rho^*(1.38\,\mu m) &= S_{0.86} \times (\rho^*(0.86\,\mu m) - \rho_R(0.86\,\mu m)) \\ &= S_{0.86} \times \rho_C(0.86\,\mu m),\end{aligned}$$

$$\rho_C(0.86\,\mu m) = \rho^*(1.38\ \mu m) / S_{0.86}$$

$$\rho_C(1.61\,\mu m) = \rho^*(1.38\ \mu m) / S_{1.61}$$

Illustration of linear relations between 1.38-micron band and a SWIR band images using a set of AVIRIS data acquired over both land & water surfaces

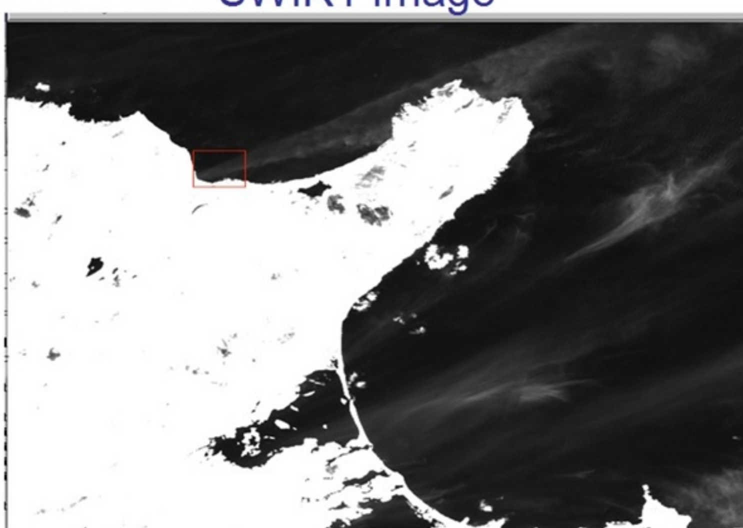


Examples of Cirrus Correction For Landsat8 Data

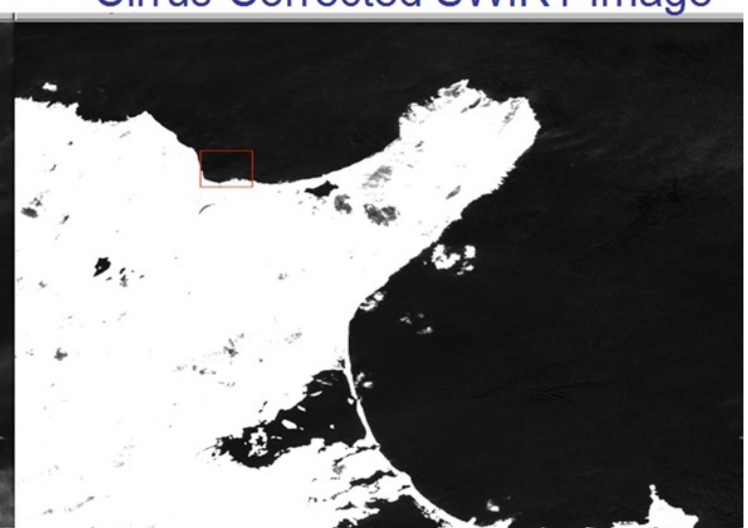
RGB Image

Cirrus-Corrected RGB Image

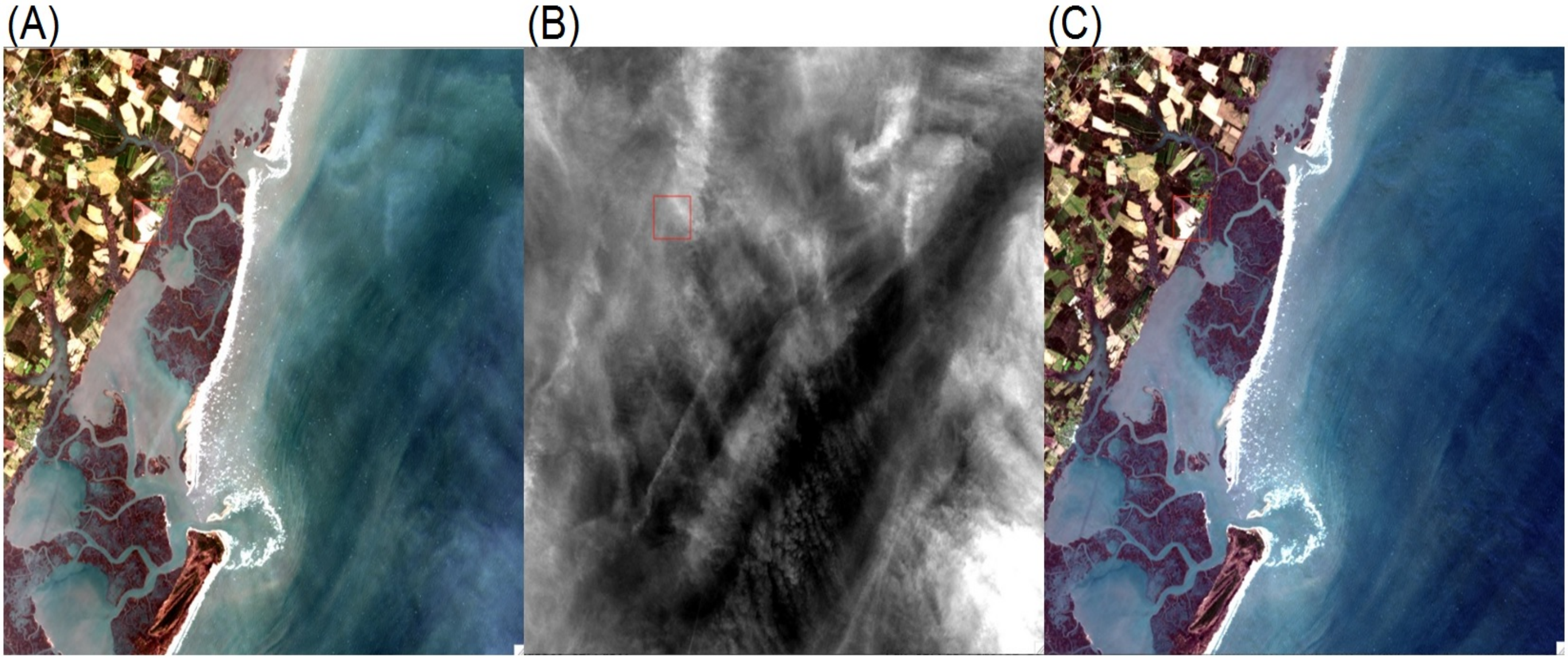
SWIR1 Image



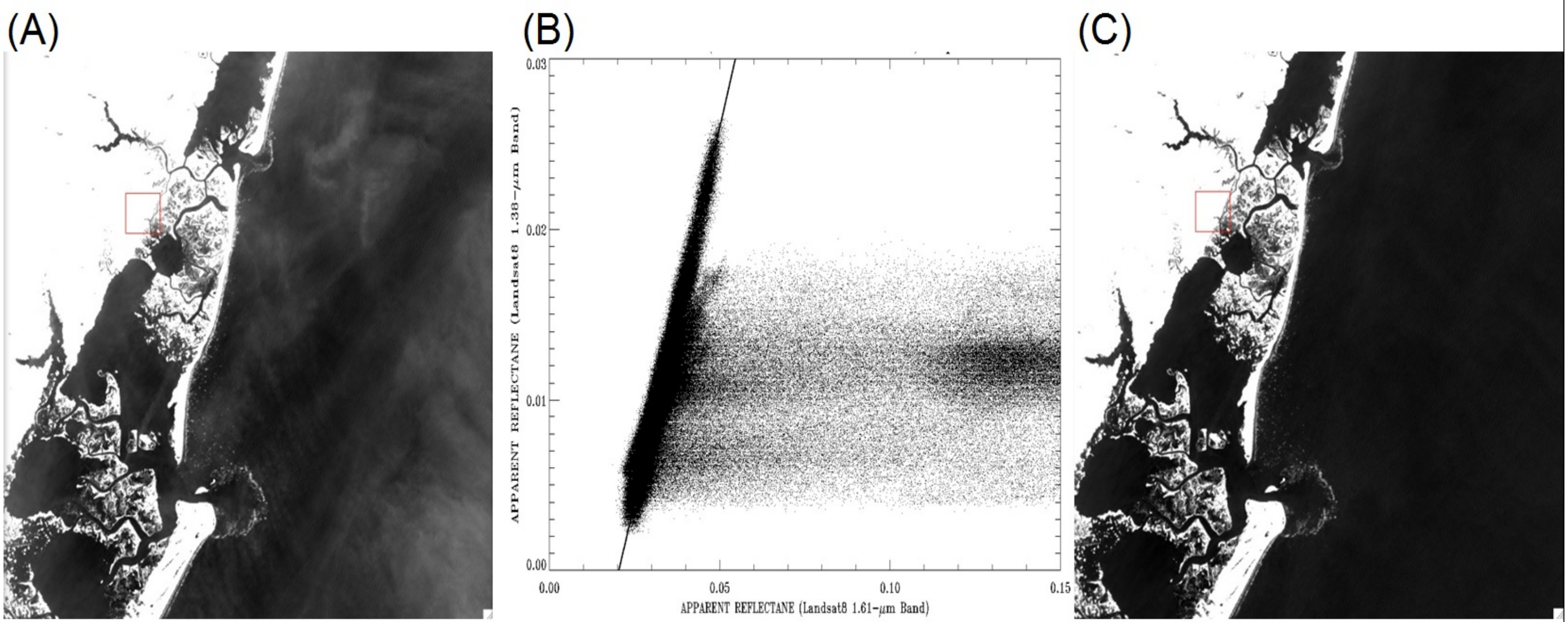
Cirrus-Corrected SWIR1 Image



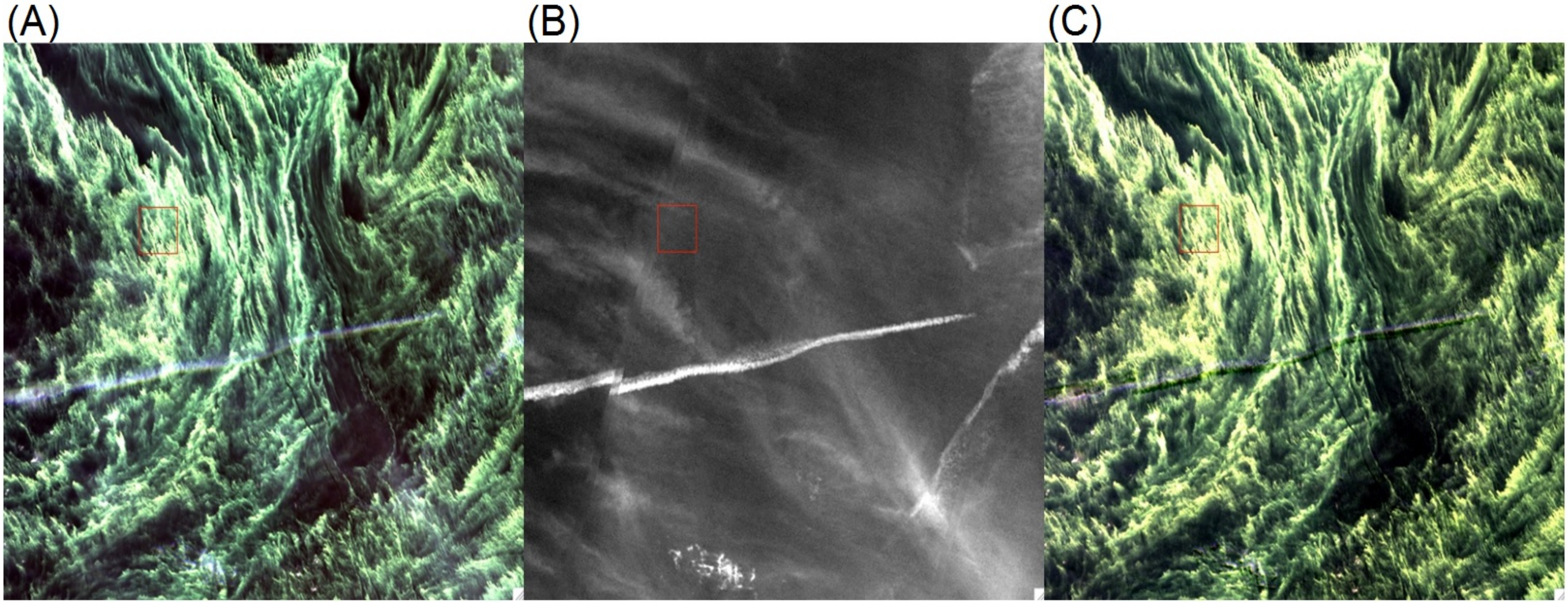
An example of cirrus correction from a L8 OLI data set acquired over US Eastern Coastal area



An example of cirrus correction for the SWIR1 Band (1.61 μm)



Parallax Effects



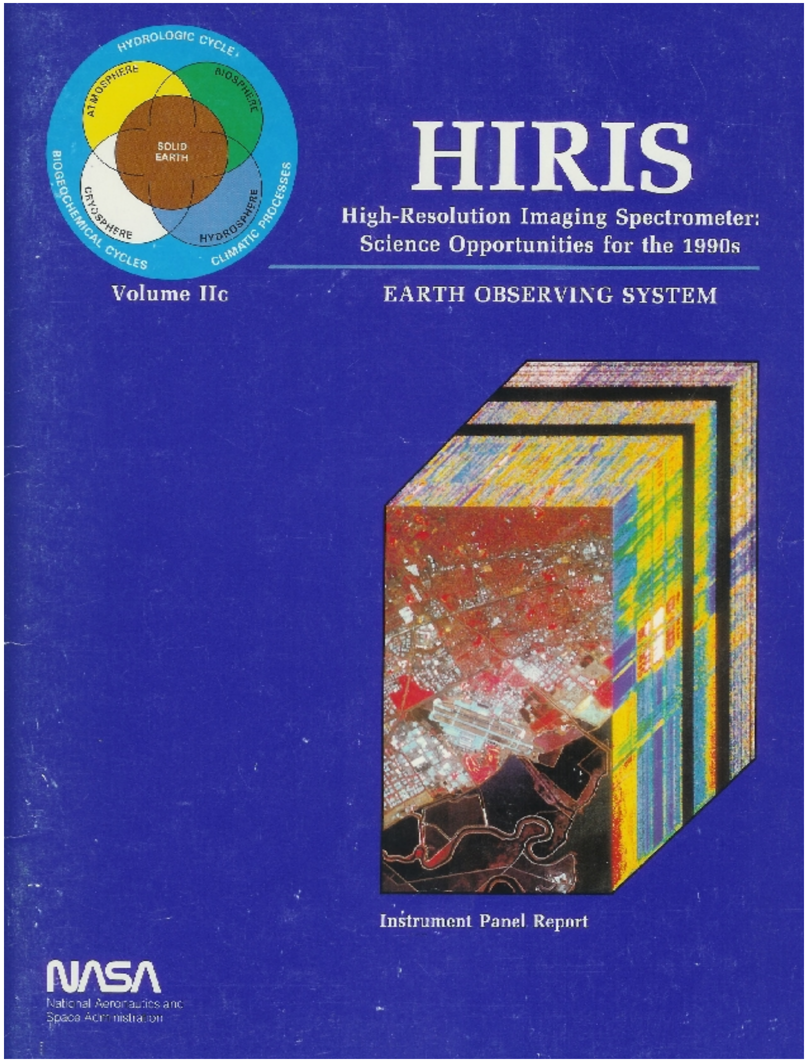
Summary

- A number of satellite instruments, including Landsat 8 OLI, have implemented the1.38-micron cirrus channels.

- We have developed an empirical technique for the removal of thin cirrus scattering effects in the 0.4 – 2.5 micron region using AVIRIS data acquired over both land and water surfaces.

- We presented results from application of the technique to a few Landsat 8 OLI data sets. The spatially diffuse cirrus clouds are removed qite well. However, due to mis-registrations of cloud features in different OLI images (resulted from the intrinsic design of the OLI focal planes), aircraft-induced contrail cirrus clouds are not well removed.

BACKUP SLIDES

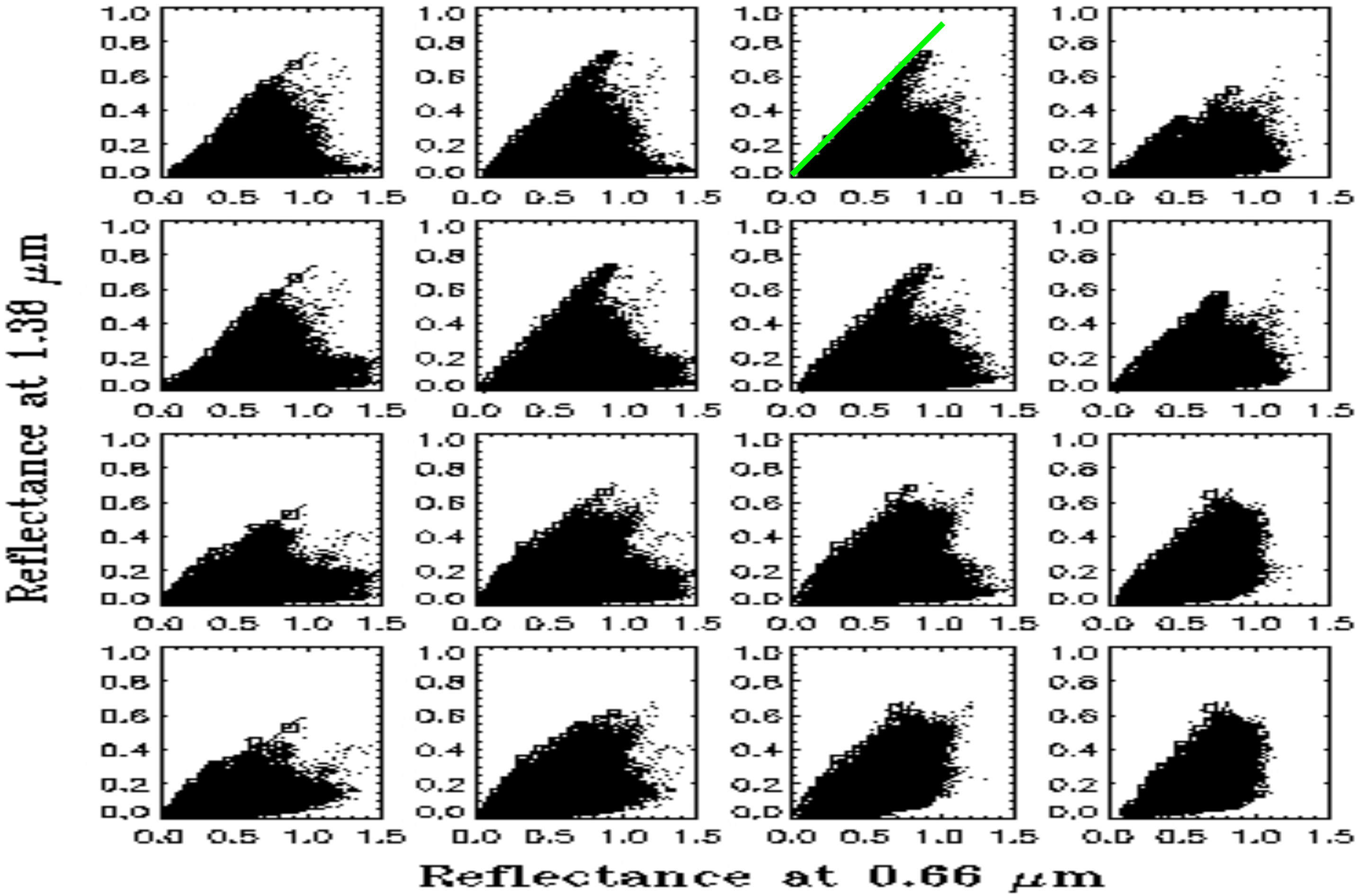


In the mid-1980s, NASA proposed a huge Earth Observing System. The original EOS included the HIRIS instrument.

During my work with Dr. Alex. Goetz at U. of Colorado, I used the NASA JPL AVIRIS data to develop algorithms for processing HIRIS data.

Through analysis of AVIRIS data, I first found that narrow channels near the strong water band centers (1.38 and 1.88 mm) are very effective in detecting thin cirrus clouds.

Estimates of 1.375-μm Channel Water Vapor Transmittance

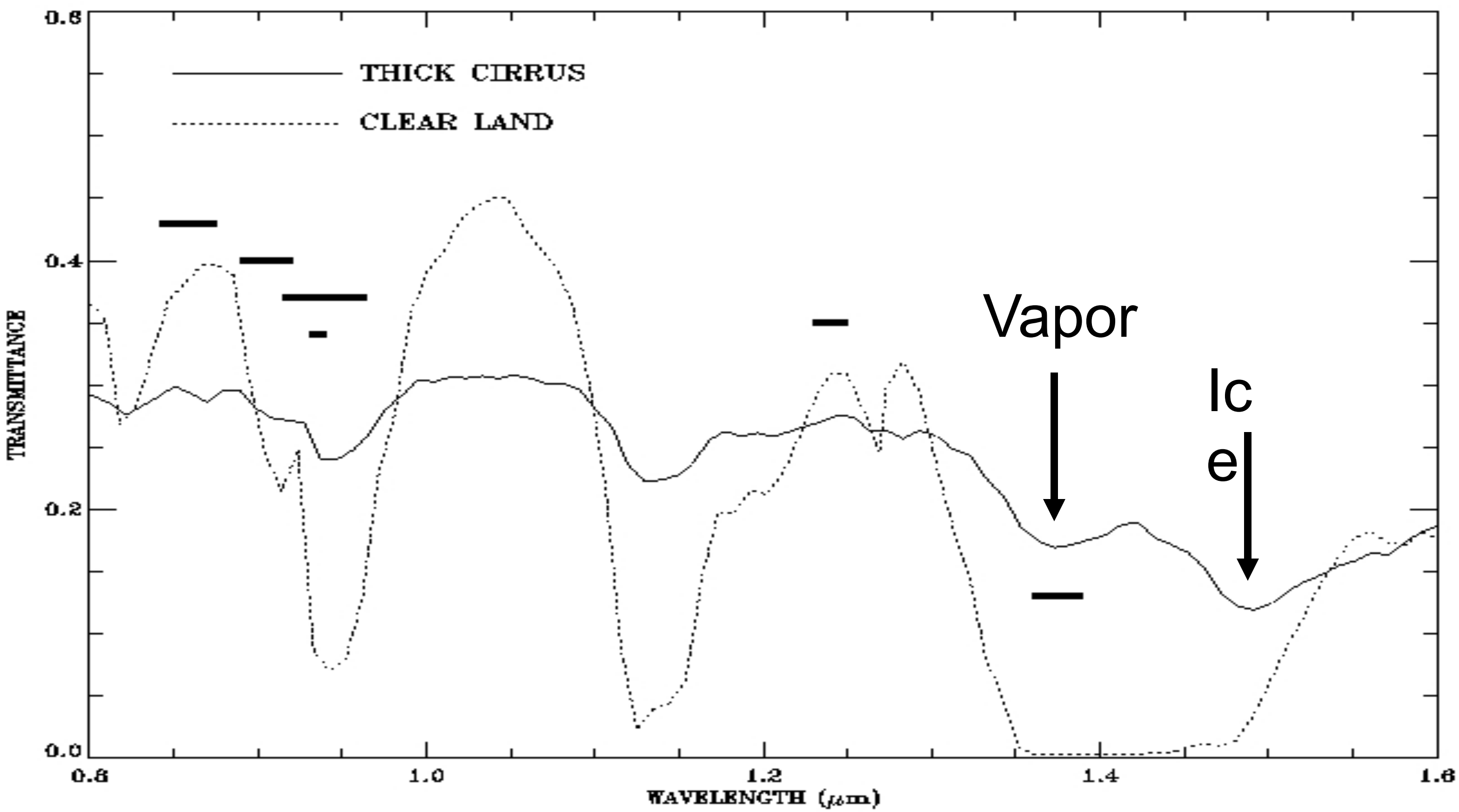


$Tran_{Vapor}$ = Slope (< 1)

$\rho_{cirr.}(Vis) = \rho_{app}(1.38)$ / Slope

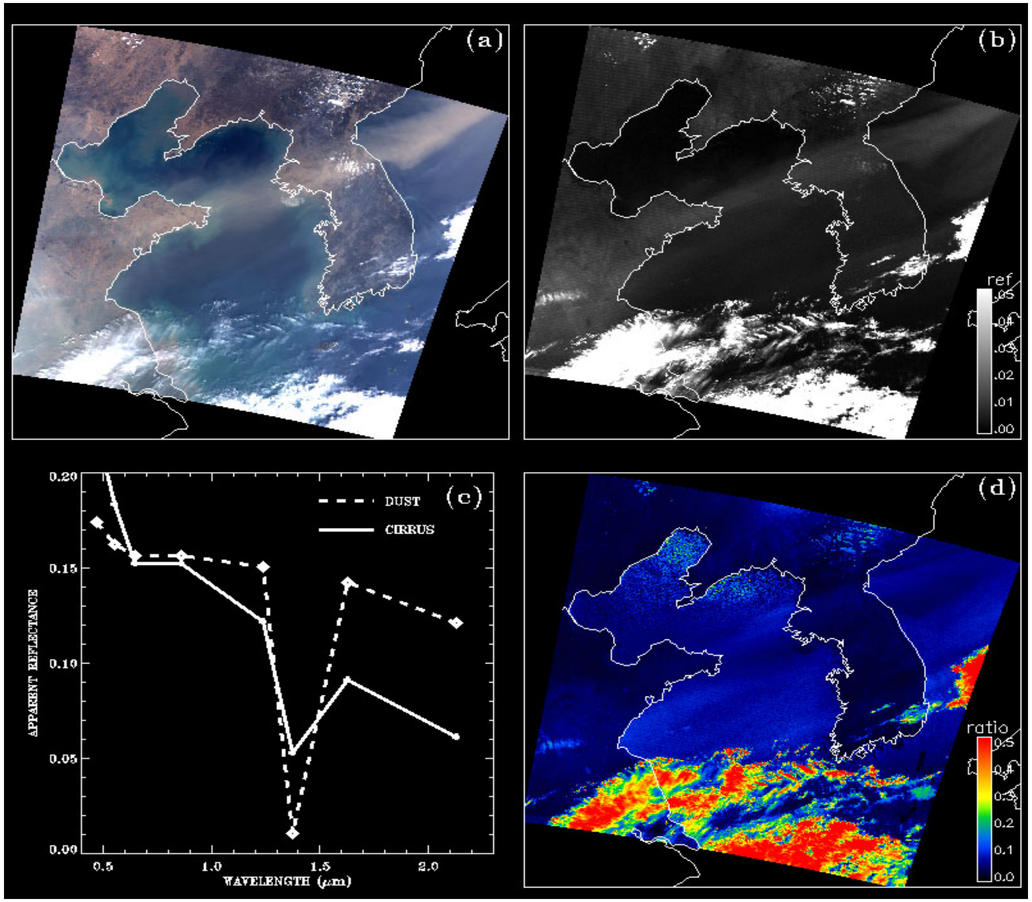
Water Vapor Absorption Effect for the 1.375-μm Channel

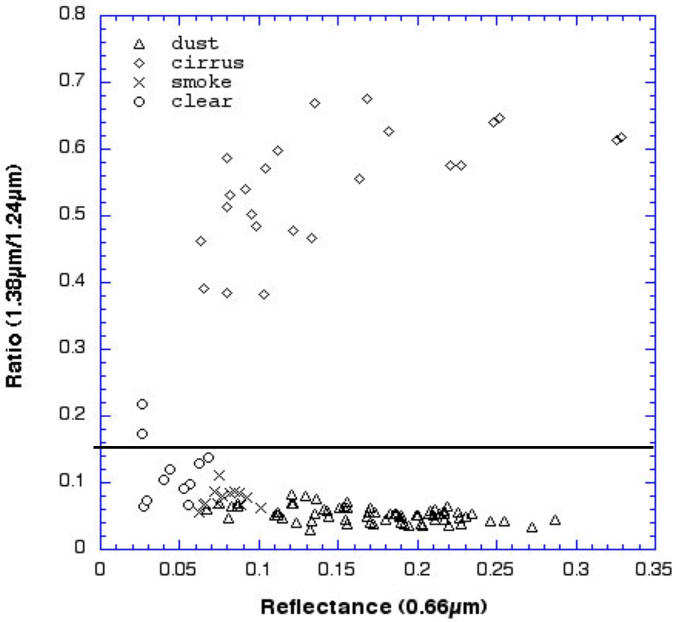
The 1.375-μm MODIS channel is affected by absorption due to water vapor above cirrus clouds. In order to use this channel for correction of cirrus effects in other atmospheric window channels, the water vapor absorption effect at 1.375-μm needs to be removed.



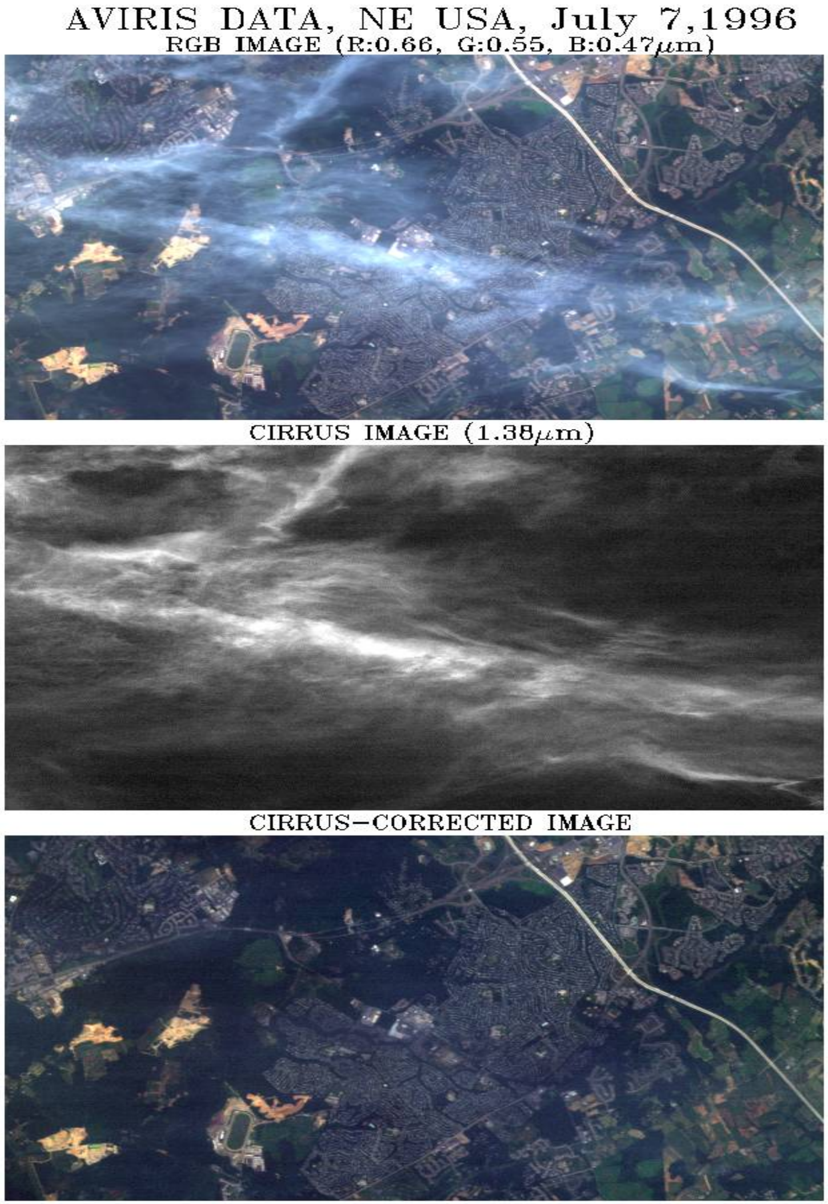
Application of the 1.38-mm Channel for Aerosol Retrievals

(a) Separating thin cirrus from dusk using the 1.38/1.24 ratio





Another example of cirrus correction using AVIRIS data



EQUATIONS

The apparent reflectance at the satellite level is defined as:

$$\rho_\lambda^* = \pi L_{c\lambda} / (\mu_0 E_0)$$

$$\rho_\lambda^* = \rho_{c\lambda} + T_{c\lambda} \rho_\lambda / (1 - S_{c\lambda} \rho_\lambda) \qquad (1)$$

$\rho_{c\lambda}$: path radiance due to cirrus;

$S_{c\lambda}$: cloud scattering of upward radiation back to surface;

ρ_λ : Surface reflectance;

If $S_{c\lambda} << 1$, Eq. (1) becomes: $\rho_\lambda^* = \rho_{c\lambda} + T_{c\lambda} \rho_\lambda$ (2)

We found an empirical relation: $\rho_{c\lambda} = \rho_{c1.375} / K_a$, (3)

where K_a is derived from a scatter plot.

Substituting Eq. (3) into (2), we get

$$T_{c\lambda} \rho_\lambda = \rho_\lambda^* - \rho_{c1.375} / K_a \qquad (4)$$

To a good approximation: $T_{c\lambda} = 1 - \rho_{c\lambda}$,

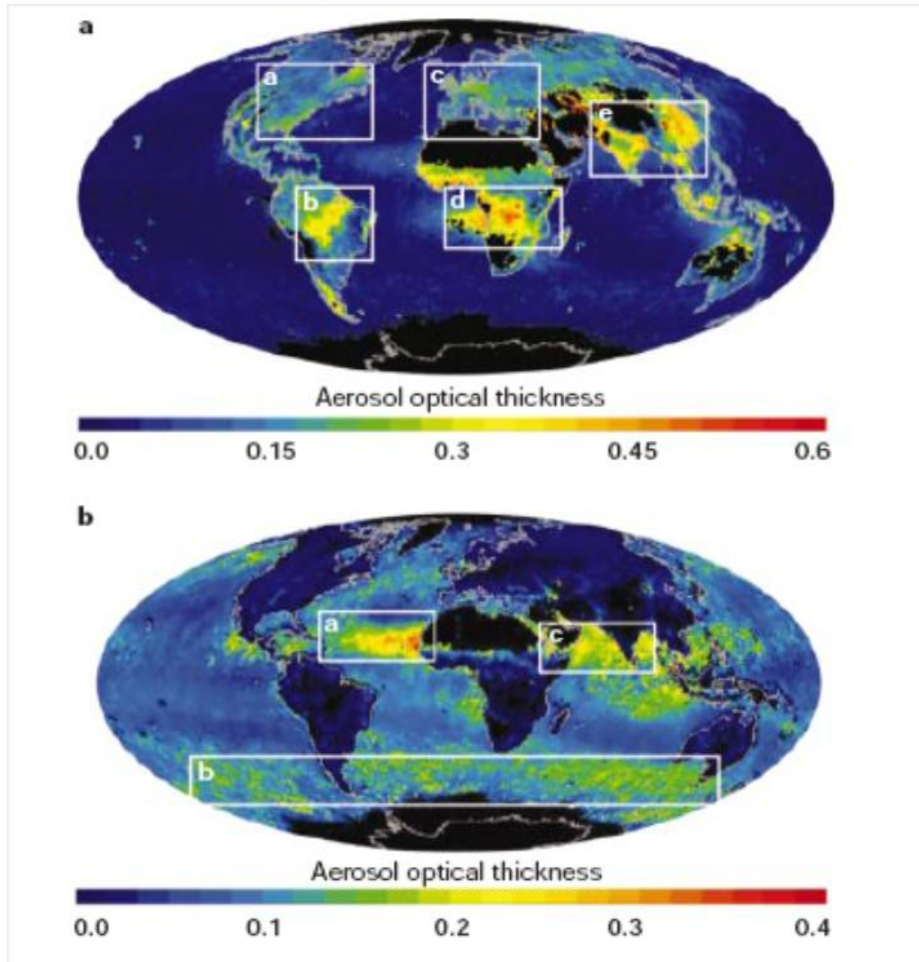
& $\rho_\lambda = [\rho_\lambda^* - \rho_{c1.375} / K_a] / (1 - \rho_{c1.375} / K_a)$ (5)

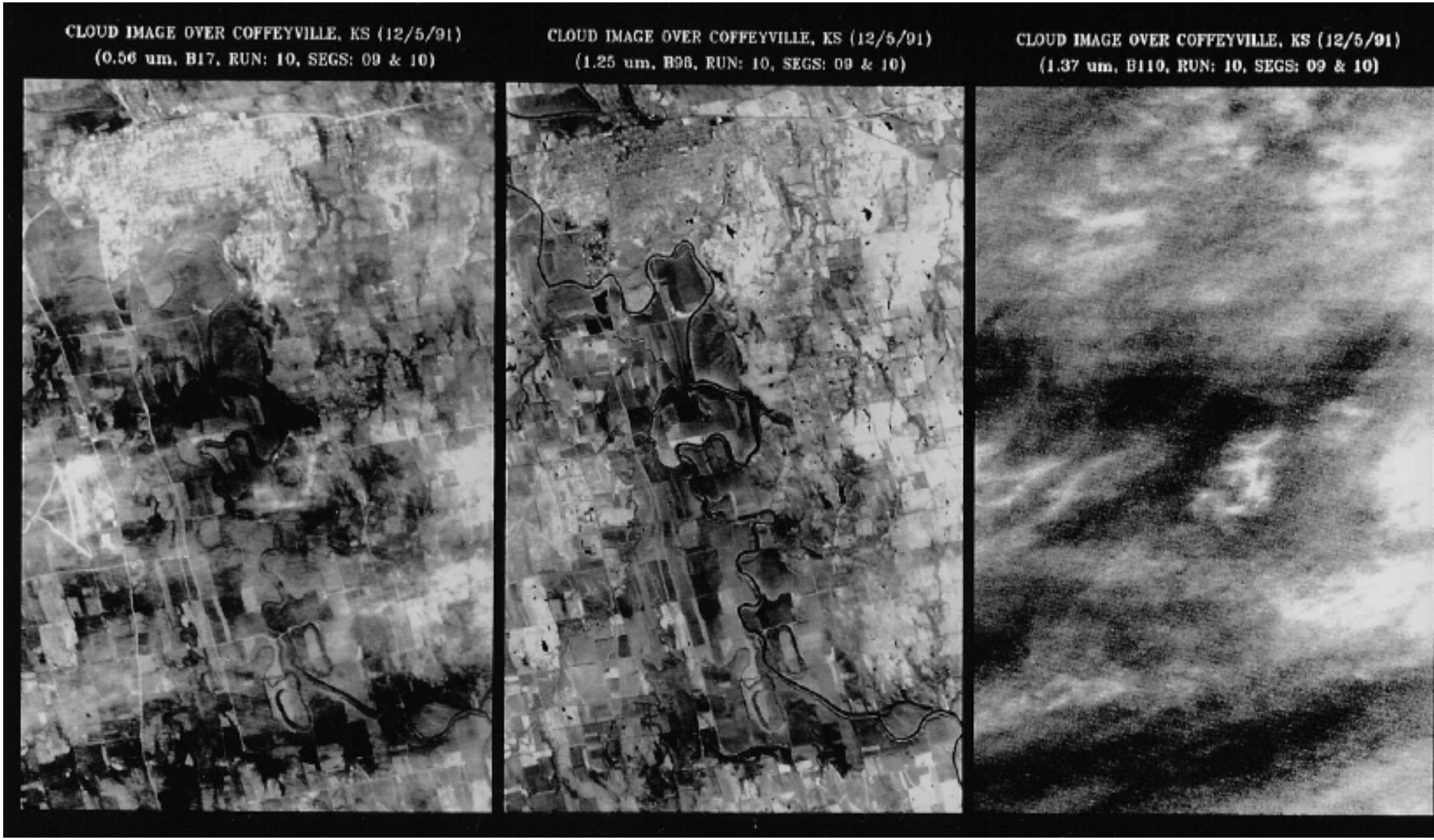
Scientifically questionable Aerosol Optical Depth Images Already Published in the “Nature” Magazine

September 2000

Aerosol Optical Depth (Fine Mode)

Aerosol Optical Depth (Coarse Mode)




CLOUD IMAGE OVER COFFEYVILLE, KS (12/5/91)
(0.56 um, B17, RUN: 10, SEGS: 09 & 10)
CLOUD IMAGE OVER COFFEYVILLE, KS (12/5/91)
(1.25 um, B98, RUN: 10, SEGS: 09 & 10)
CLOUD IMAGE OVER COFFEYVILLE, KS (12/5/91)
(1.37 um, B110, RUN: 10, SEGS: 09 & 10)