MODIS THIN CIRRUS REFLECTANCE ALGORITHM USING THE 1.375-μM CHANNEL

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OUTLINE

- Detection of thin cirrus clouds using the 1.375-µm Channel
- An empirical technique for correction of thin cirrus effects
- Sample results
- Quantitative improvement to NDVI estimation
- A preliminary atmosphere removal algorithm (ATREM) for hyperspectral remote sensing of coastal water
- Discussions and summary

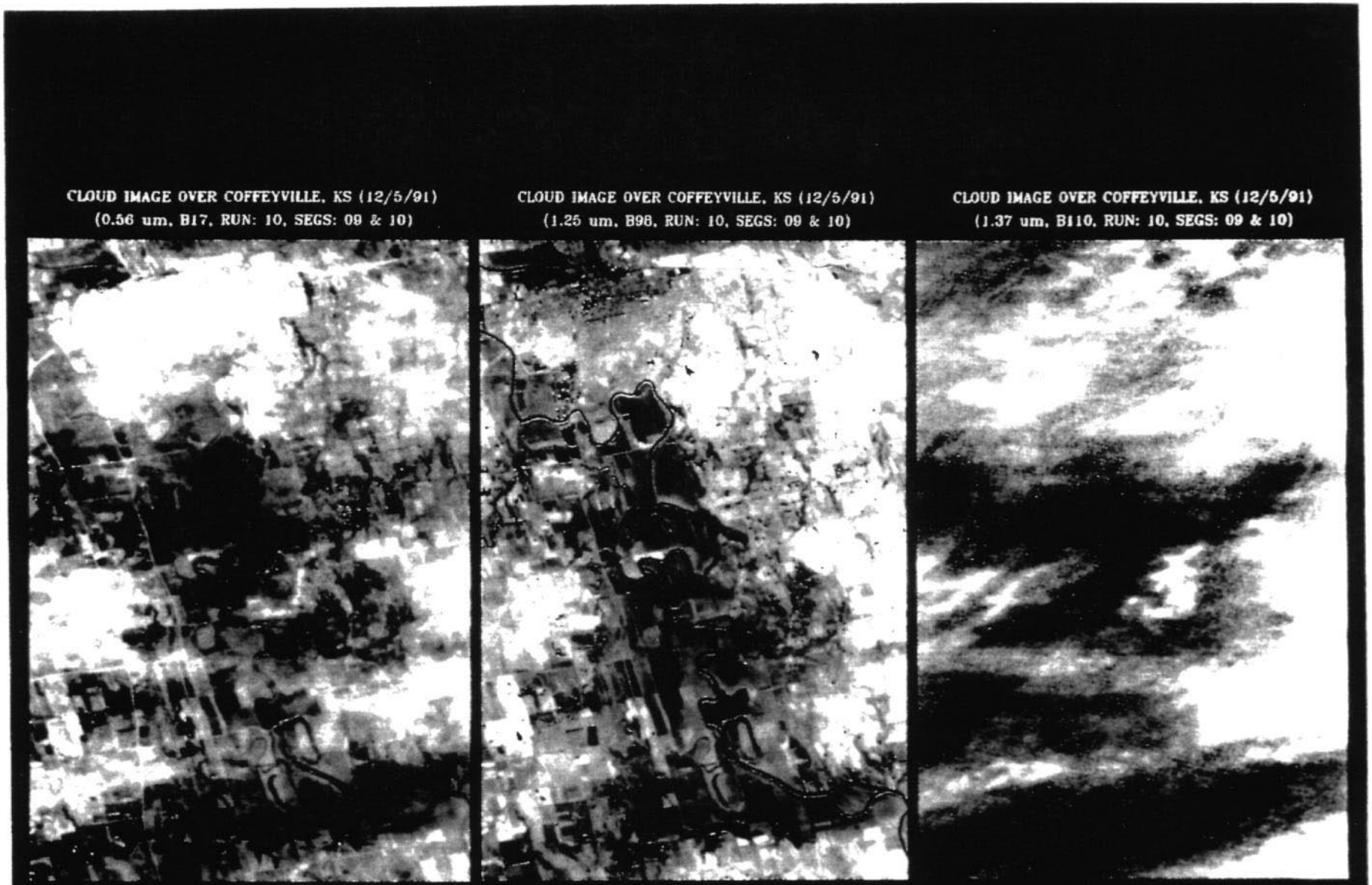
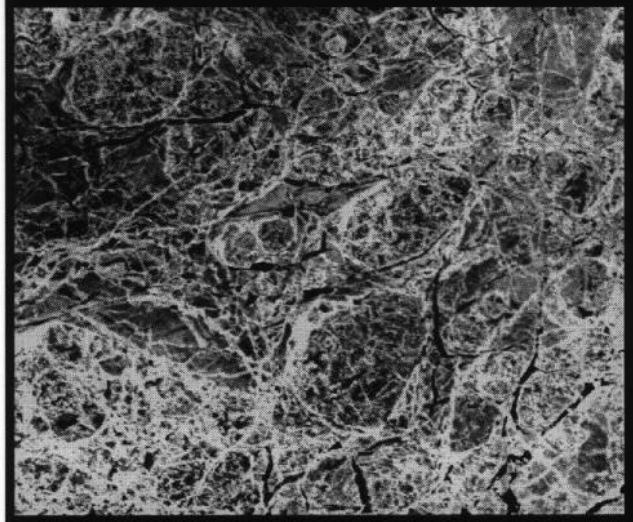


Fig. 1: Examples of AVIRIS images acquired over Coffeyville in southeastern Kansas on Dec. 5, 1991. Both the 0.56-µm and 1.25-µm images show surface features, while the 1.37-µm image shows only upper level cirrus clouds.

AVIRIS IMAGE OVER SEA ICE IN ALASKA (6/95)
(AVIRIS Channel 29, 0.66 μm)



(NAVAL RESEARCH LAB, DC)

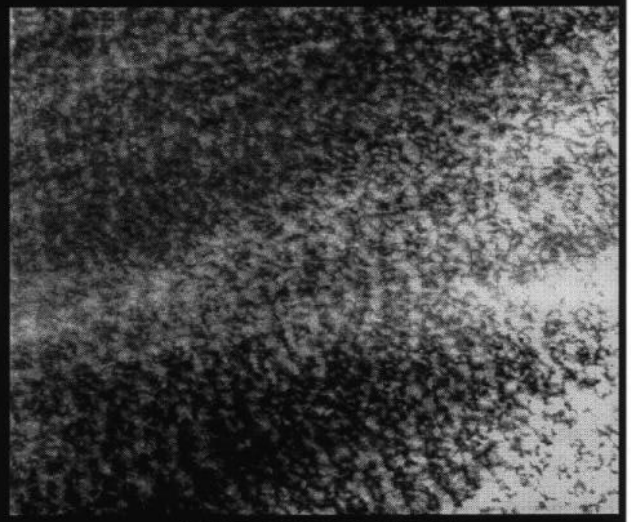
AVIRIS IMAGE OVER SEA ICE IN ALASKA (6/95)
(AVIRIS Channel 110, 1.38 μm)

(NAVAL RESEARCH LAB, DC)

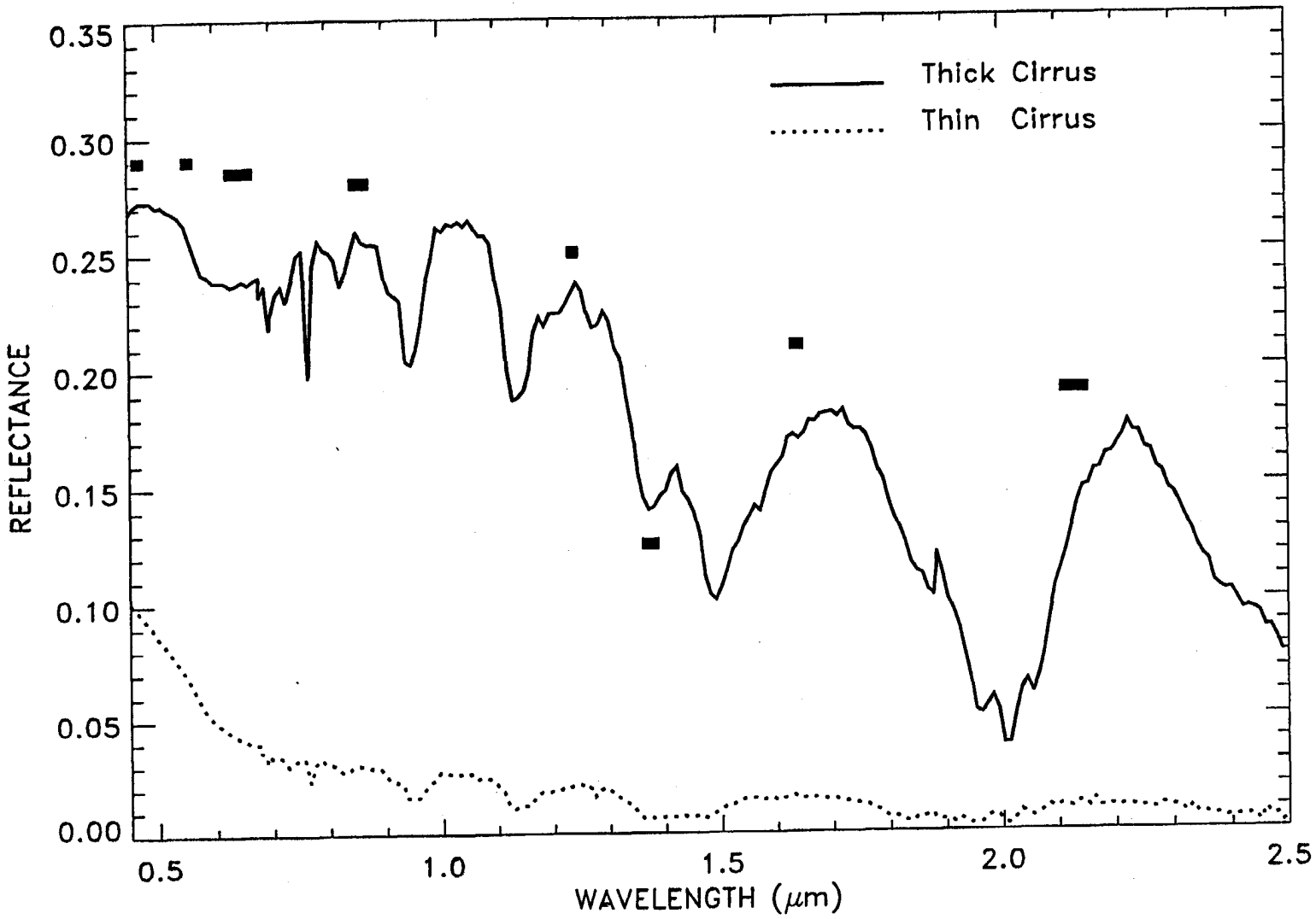
AVIRIS IMAGE OVER SEA ICE IN ALASKA (6/95)
(AVIRIS Channel 117, 1.46 μm)

(NAVAL RESEARCH LAB, DC)

AVIRIS IMAGE OVER SEA ICE IN ALASKA (6/95)
(AVIRIS Channel 136, 1.64 μm)



(NAVAL RESEARCH LAB, DC)


Thick Cirrus
Thin Cirrus
REFLECTANCE
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.5
1.0
1.5
2.0
2.5
WAVELENGTH (μm)

EQUATIONS

We define the apparent reflectance at the satellite level as:

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

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

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

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

ρ_λ : Surface reflectance

If $S_{c\lambda} << 1$, then Eq. (1) becomes

$$\rho_\lambda^* = \rho_{c\lambda} + T_{c\lambda} \rho_\lambda \quad (2)$$

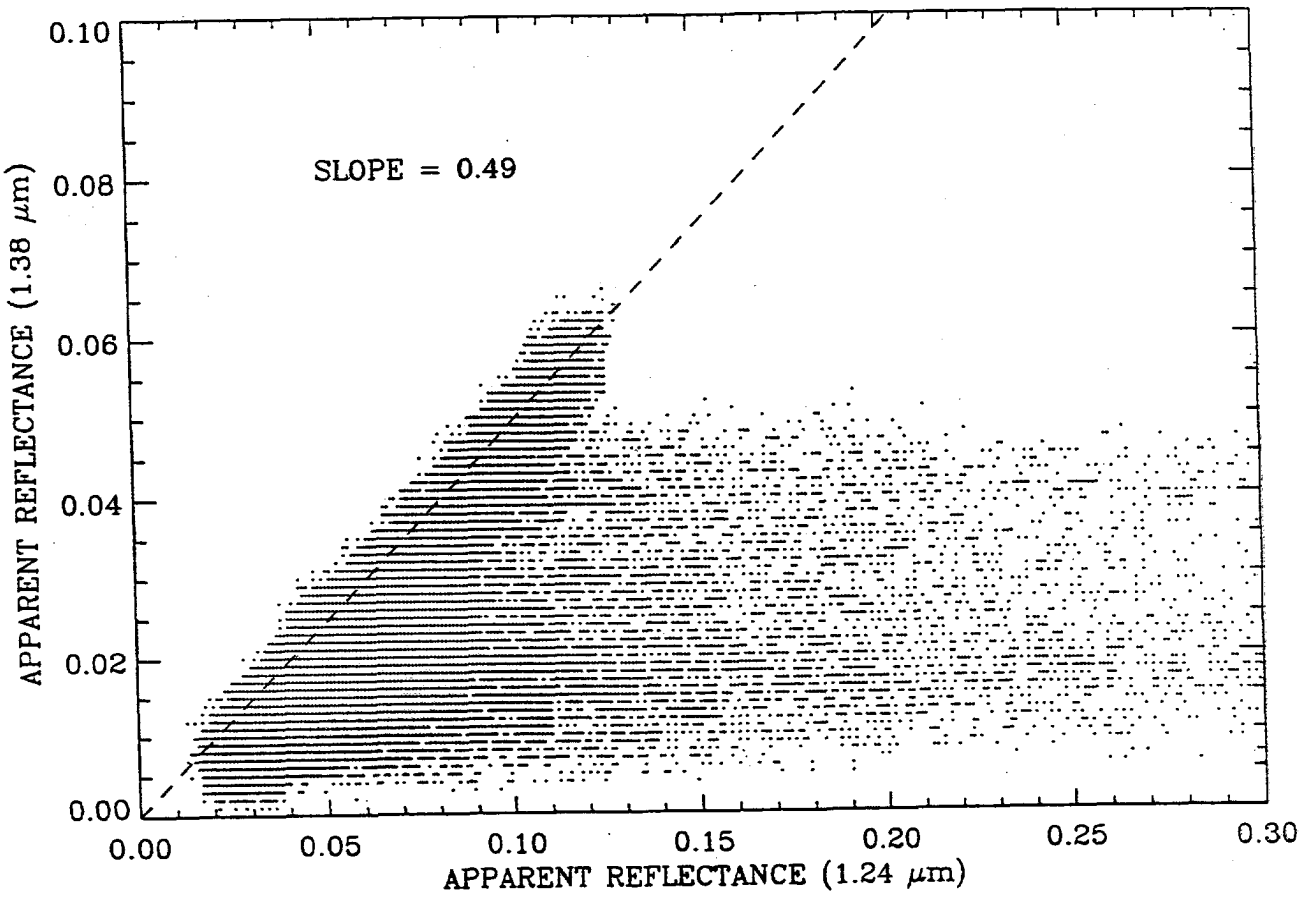
We found an empirical relation:

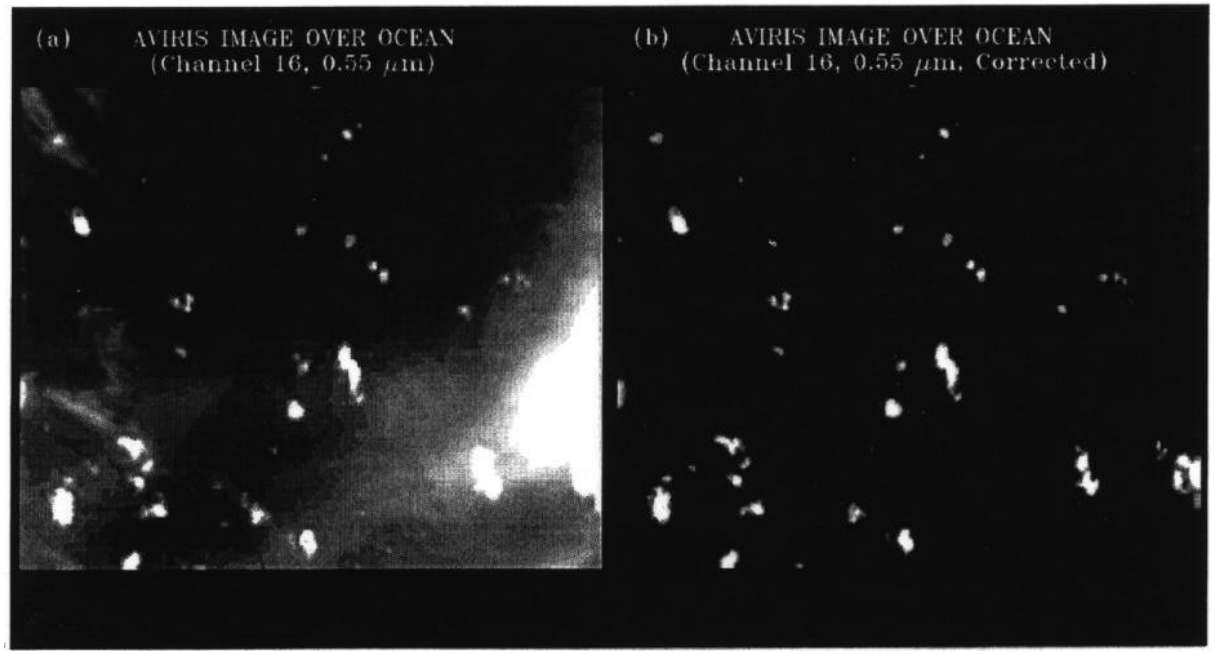
$$\rho_{c\lambda} = \rho_{c1.375} / K_a \quad (3)$$

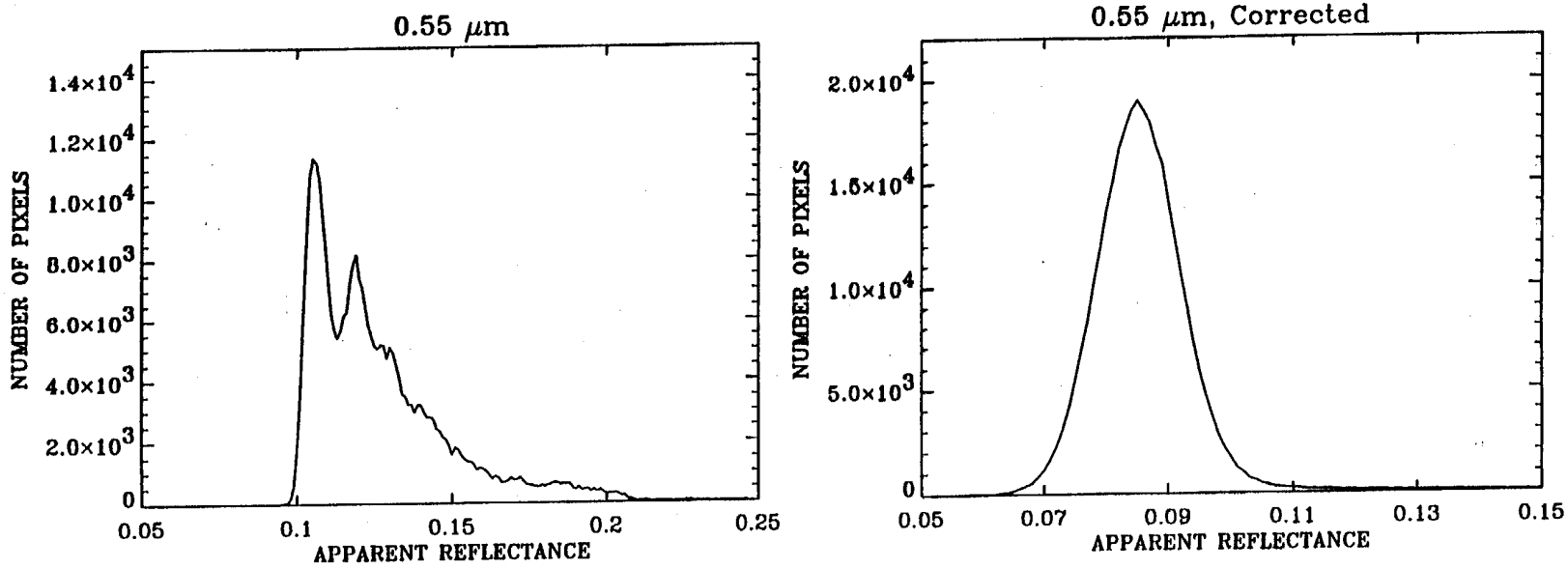
K_a is a function of water vapor above & within cirrus clouds

Substituting (3) into (2), we get

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


SLOPE = 0.49
APPARENT REFLECTANCE (1.38 μm)
APPARENT REFLECTANCE (1.24 μm)
0.00
0.02
0.04
0.06
0.08
0.10
0.00
0.05
0.10
0.15
0.20
0.25
0.30


(a) AVIRIS IMAGE OVER OCEAN
(Channel 16, 0.55 μm)
(b) AVIRIS IMAGE OVER OCEAN
(Channel 16, 0.55 μm, Corrected)


0.55 μm
NUMBER OF PIXELS
1.4×10^4
1.2×10^4
1.0×10^4
8.0×10^3
6.0×10^3
4.0×10^3
2.0×10^3
0
0.05
0.1
0.15
0.2
0.25
APPARENT REFLECTANCE
0.55 μm, Corrected
NUMBER OF PIXELS
2.0×10^4
1.5×10^4
1.0×10^4
5.0×10^3
0
0.05
0.07
0.09
0.11
0.13
0.15
APPARENT REFLECTANCE

AVIRIS IMAGES OVER MONTEREY, CA

(09/04/92)

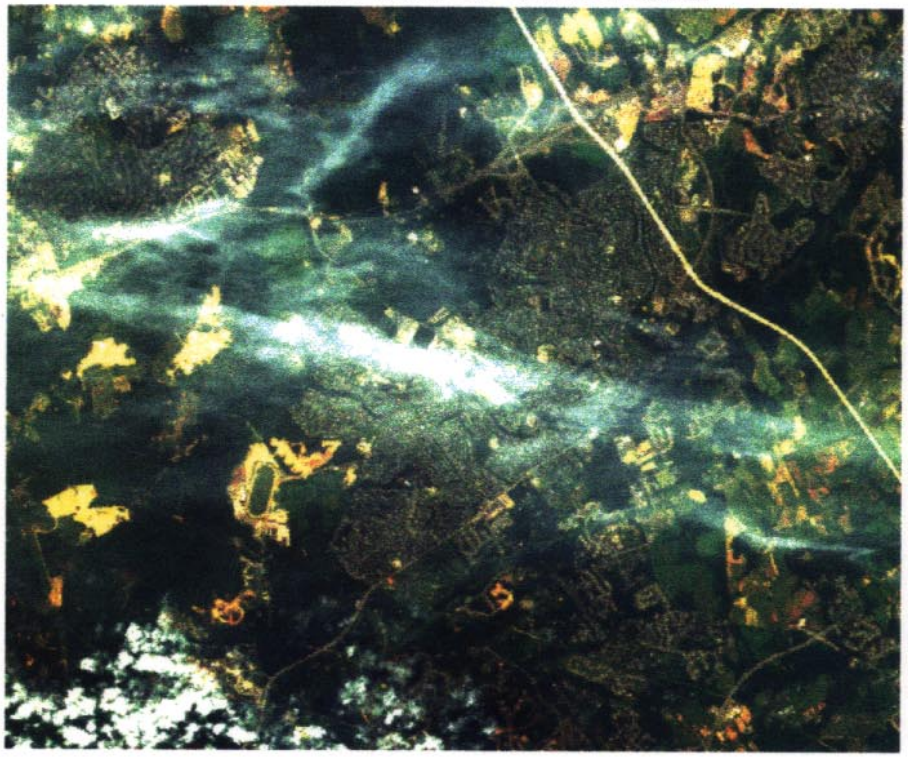
0.648 μm

1.373 μm

0.648 μm, Corrected

AV960707R5-S4

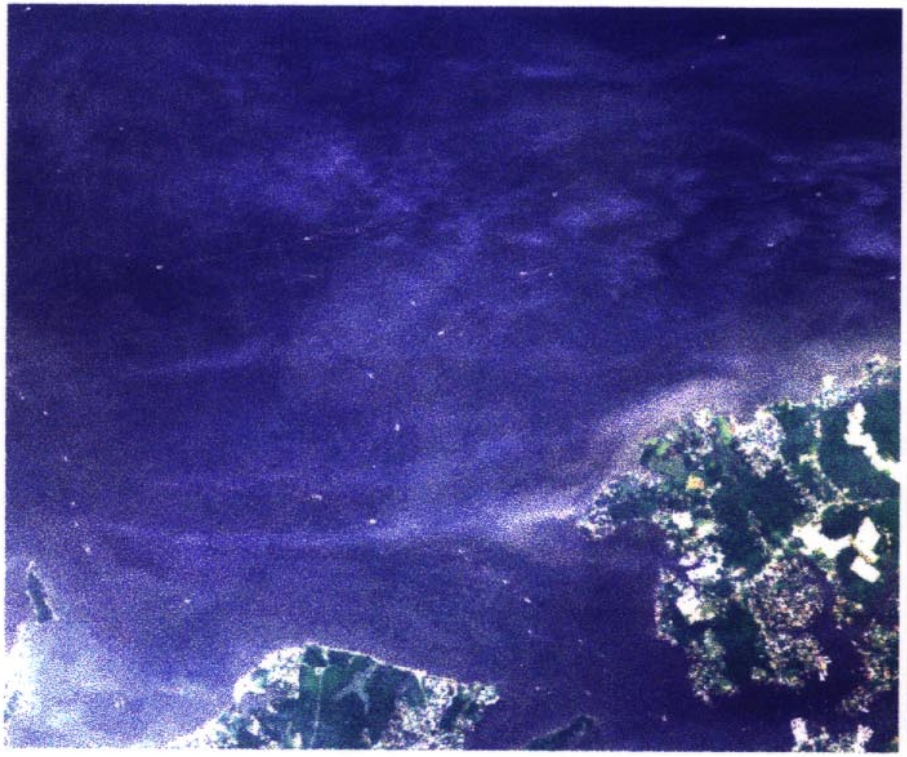
without cirrus correction



with cirrus correction

AV960707R5-S1

without cirrus correction



with cirrus correction

NDVI

For clear days,

$$NDVI_{clear} = (\rho^*_{0.86clear} - \rho^*_{0.66clear}) / (\rho^*_{0.86clear} + \rho^*_{0.66clear})$$

For thin cirrus days,

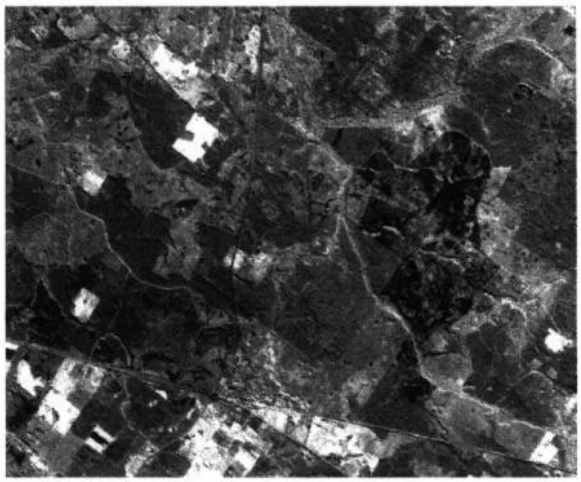
$$\rho^*_{0.86} = \rho^*_{0.86clear} + \rho_c$$

$$\rho^*_{0.66} = \rho^*_{0.66clear} + \rho_c$$

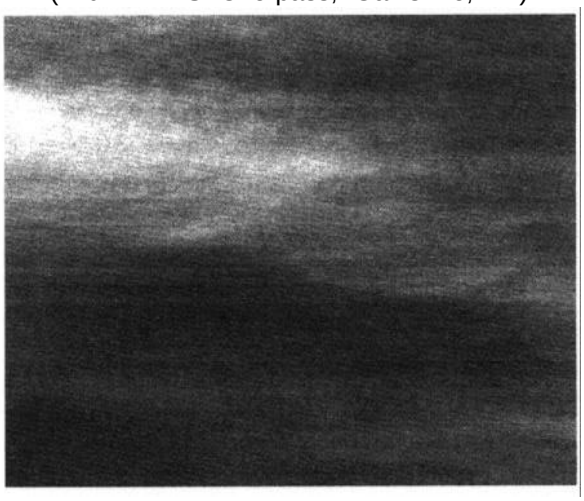
$$NDVI_{cirrus} = (\rho^*_{0.86clear} - \rho^*_{0.66clear}) / (\rho^*_{0.86clear} + \rho^*_{0.66clear} + 2\rho_c)$$

$$NDVI_{cirrus} < NDVI\ clear$$

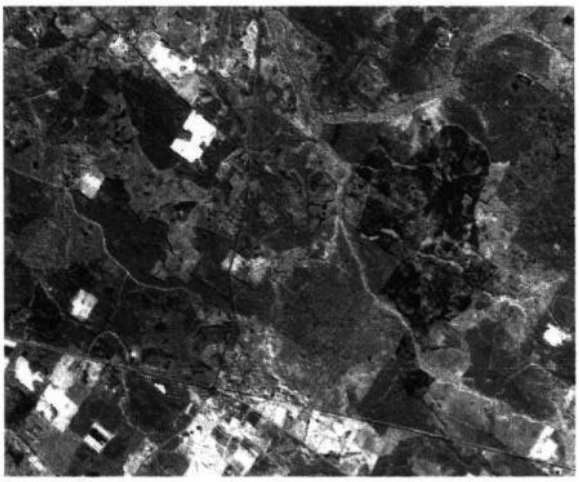
(A) 0.86 Micrometer Image
(2nd AVIRIS Overpass, Gainsville, FL)



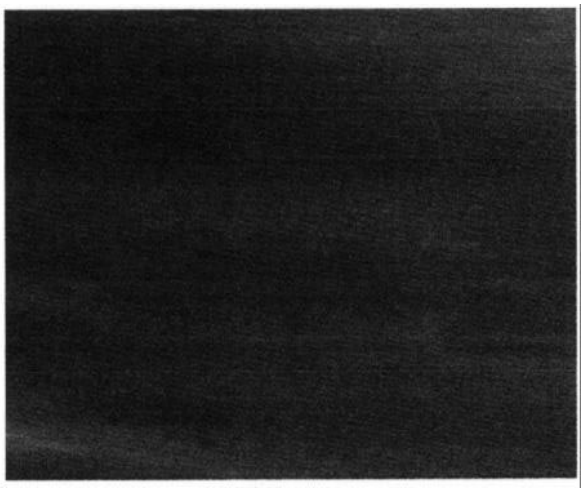
(B) 1.38 Micrometer Image
(2nd AVIRIS Overpass, Gainsville, FL)

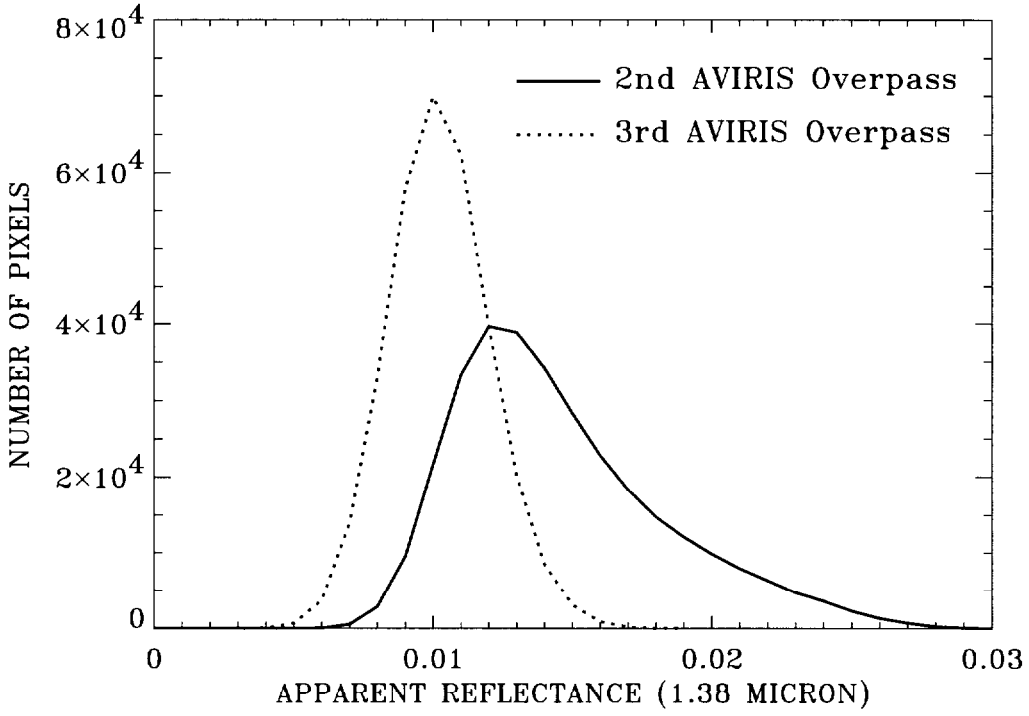


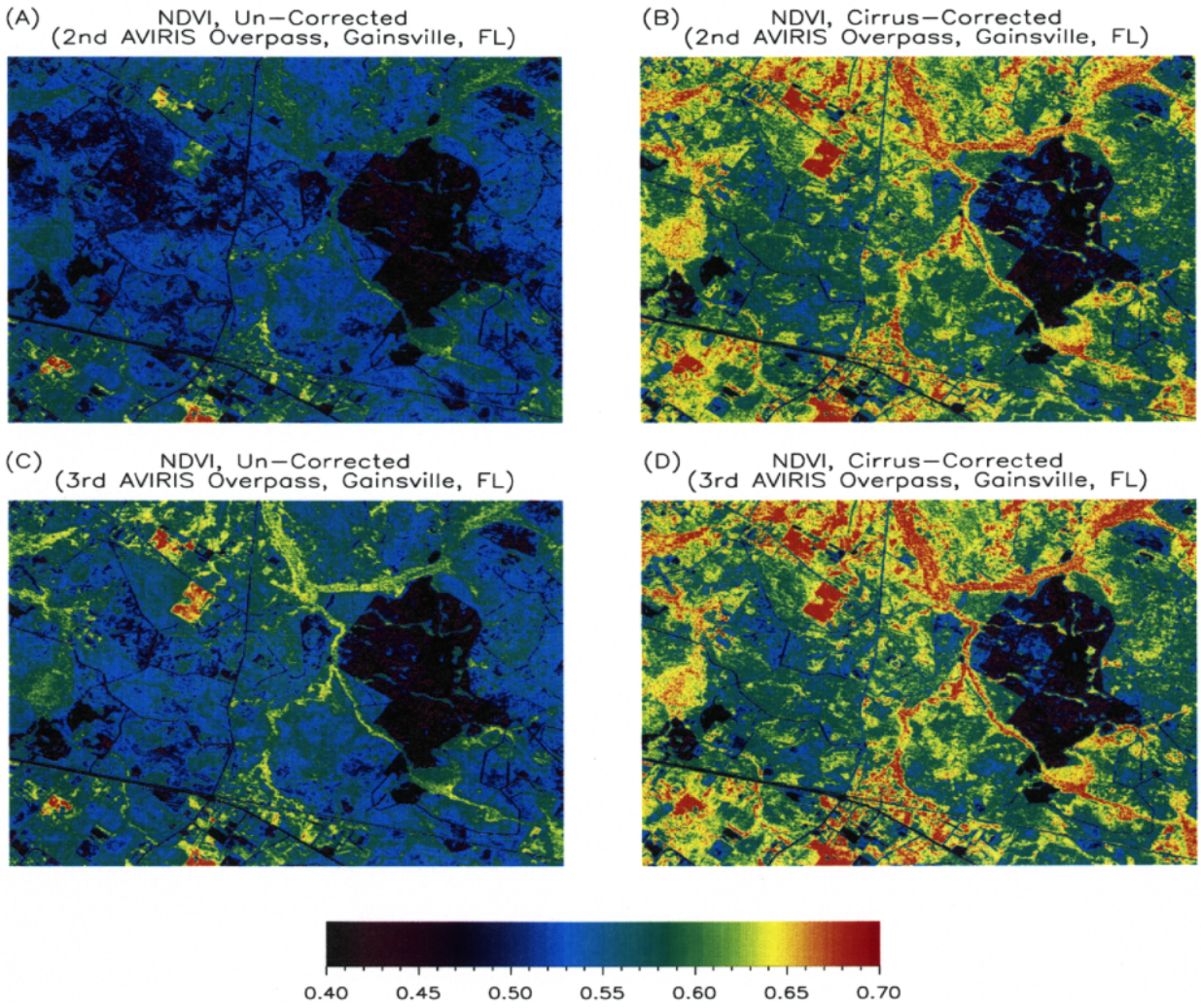
(C) 0.86 Micrometer Image
(3rd AVIRIS Overpass, Gainsville, FL)

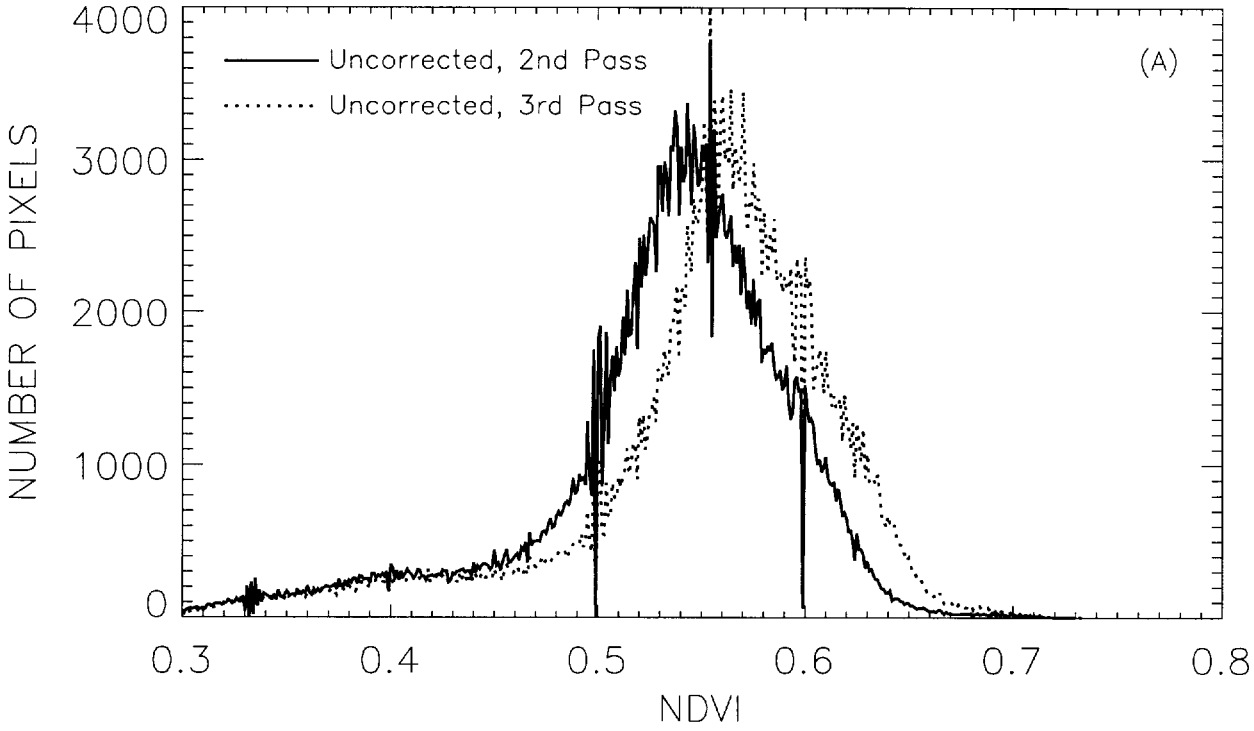


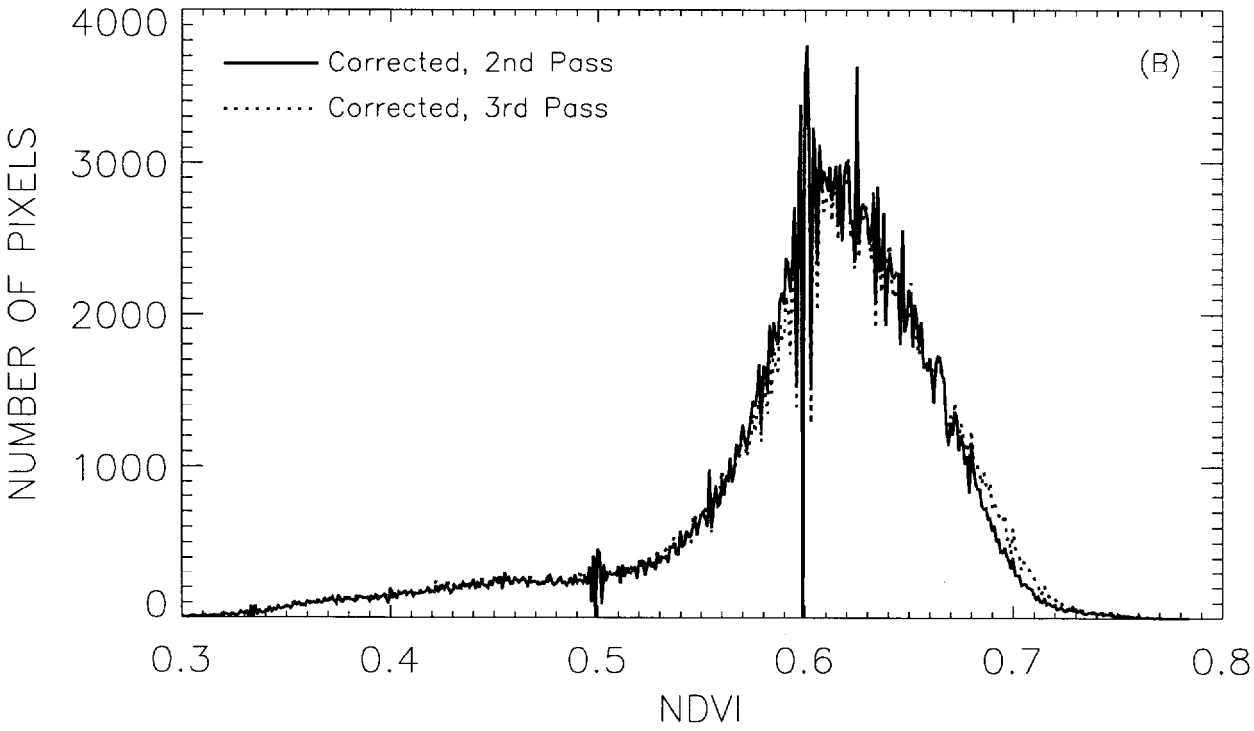
(D) 1.38 Micrometer Image
(3rd AVIRIS Overpass, Gainsville, FL)




8×10^4
6×10^4
4×10^4
2×10^4
0
NUMBER OF PIXELS
2nd AVIRIS Overpass
3rd AVIRIS Overpass
0
0.01
0.02
0.03
APPARENT REFLECTANCE (1.38 MICRON)


(A)
NDVI, Un–Corrected
(2nd AVIRIS Overpass, Gainsville, FL)
(B)
NDVI, Cirrus–Corrected
(2nd AVIRIS Overpass, Gainsville, FL)
(C)
NDVI, Un–Corrected
(3rd AVIRIS Overpass, Gainsville, FL)
(D)
NDVI, Cirrus–Corrected
(3rd AVIRIS Overpass, Gainsville, FL)
0.40
0.45
0.50
0.55
0.60
0.65
0.70

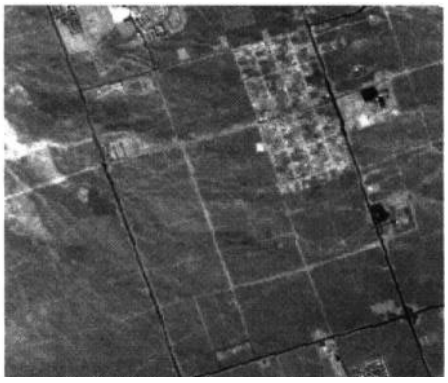

Uncorrected, 2nd Pass
Uncorrected, 3rd Pass
(A)
NUMBER OF PIXELS
4000
3000
2000
1000
0
0.3
0.4
0.5
0.6
0.7
0.8
NDVI


Corrected, 2nd Pass
Corrected, 3rd Pass
(B)
NUMBER OF PIXELS
4000
3000
2000
1000
0
0.3
0.4
0.5
0.6
0.7
0.8
NDVI

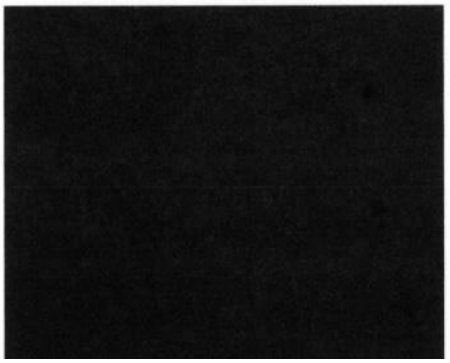
(A) 0.86 Micrometer Image
(3rd Pass, Palmdale, CA

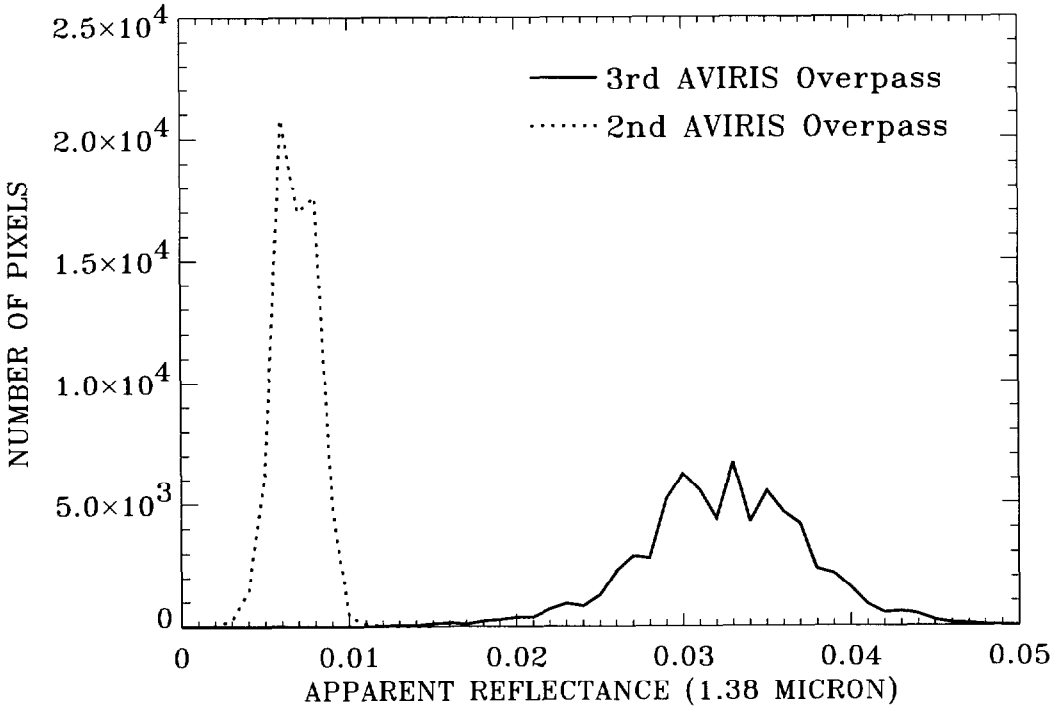
(B) 1.38 Micrometer Image
(3rd Pass, Palmdale, CA)

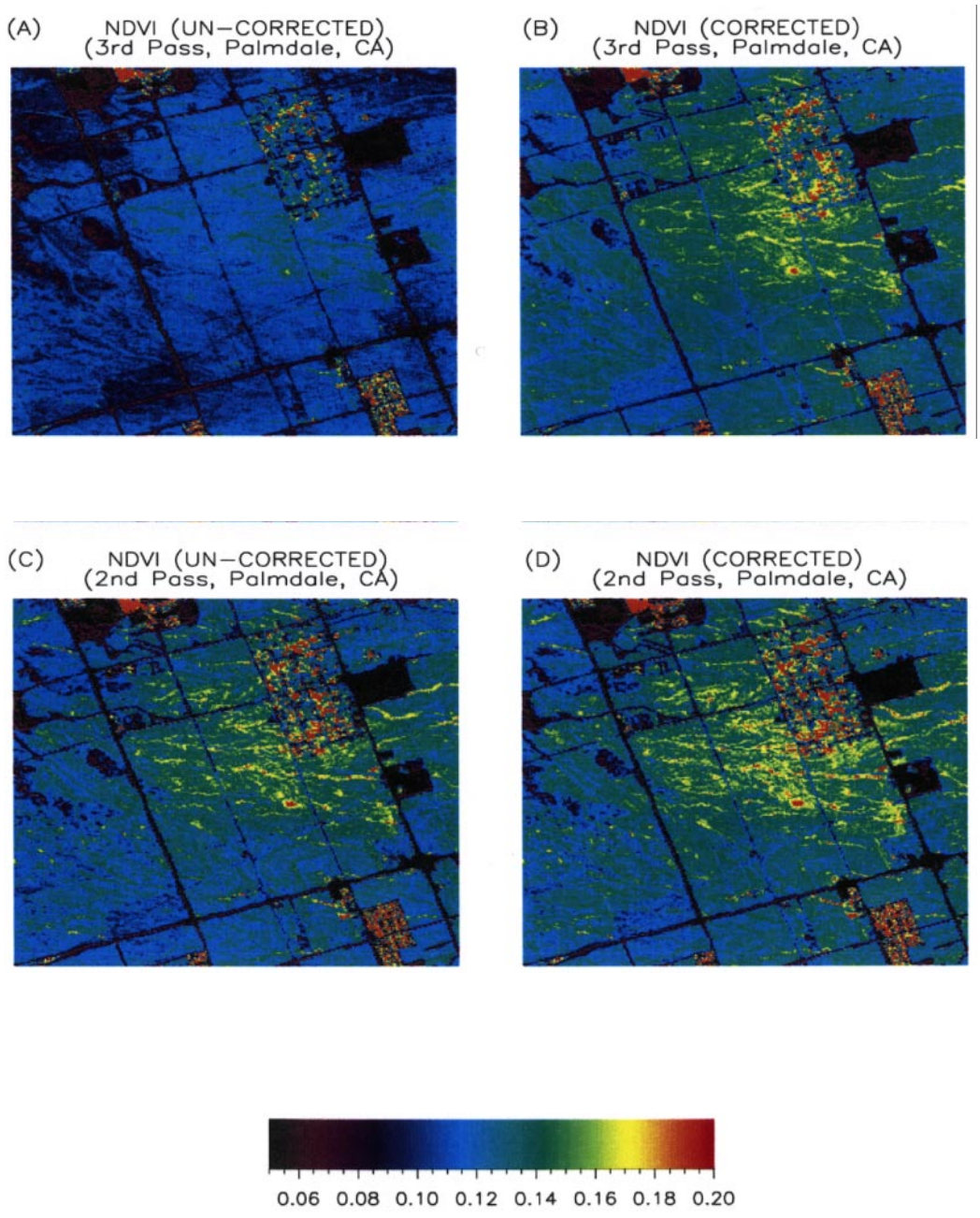
(C) 0.86 Micrometer Image
(2nd Pass, Palmdale, CA)

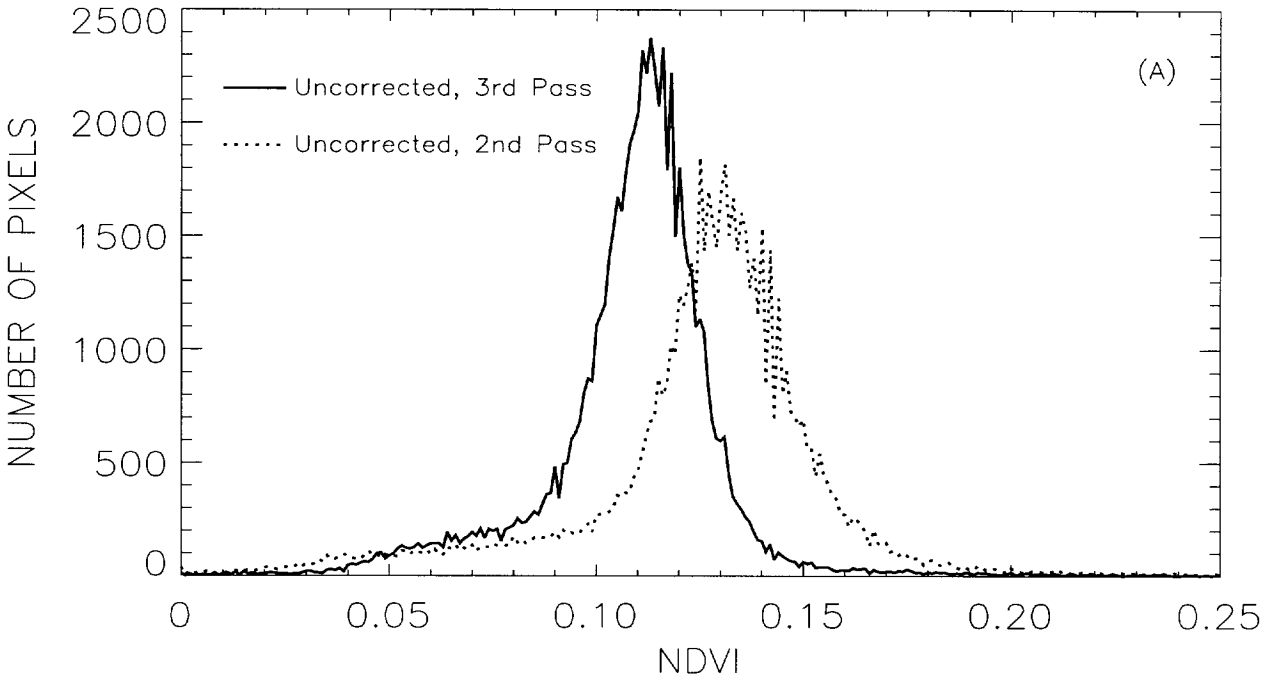


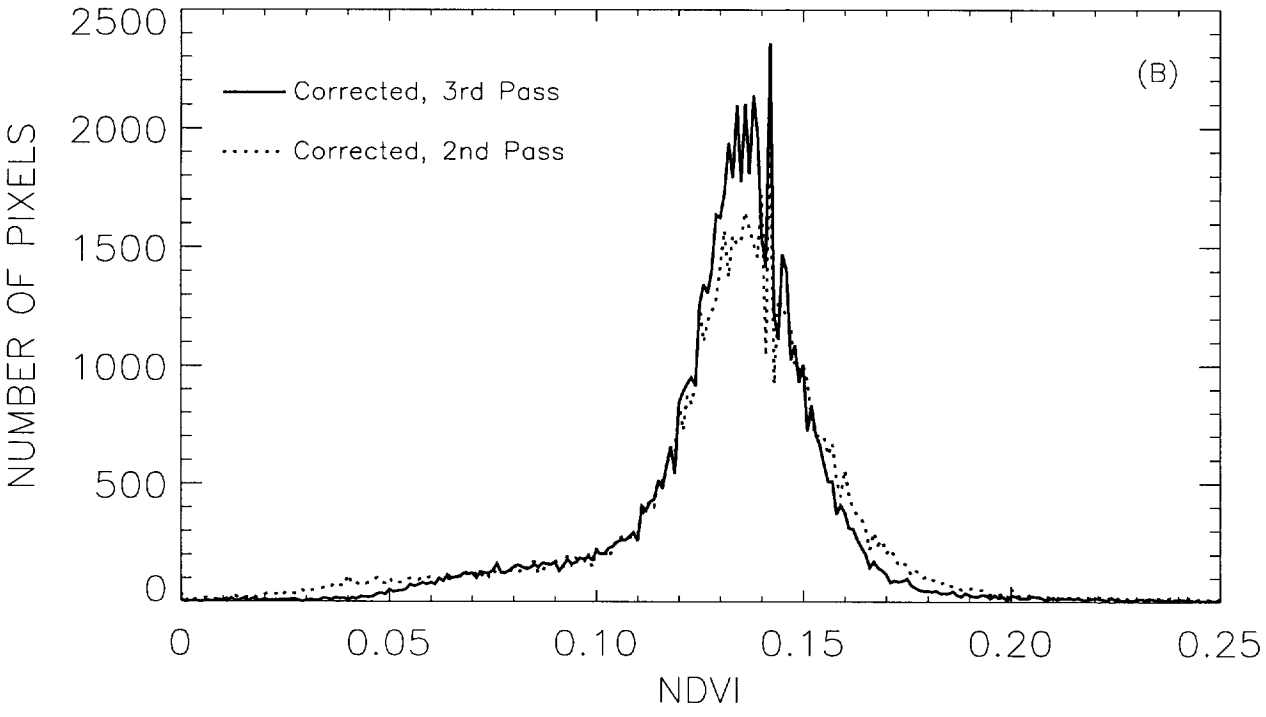
(D) 1.38 Micrometer Image
(2nd Pass, Palmdale, CA)

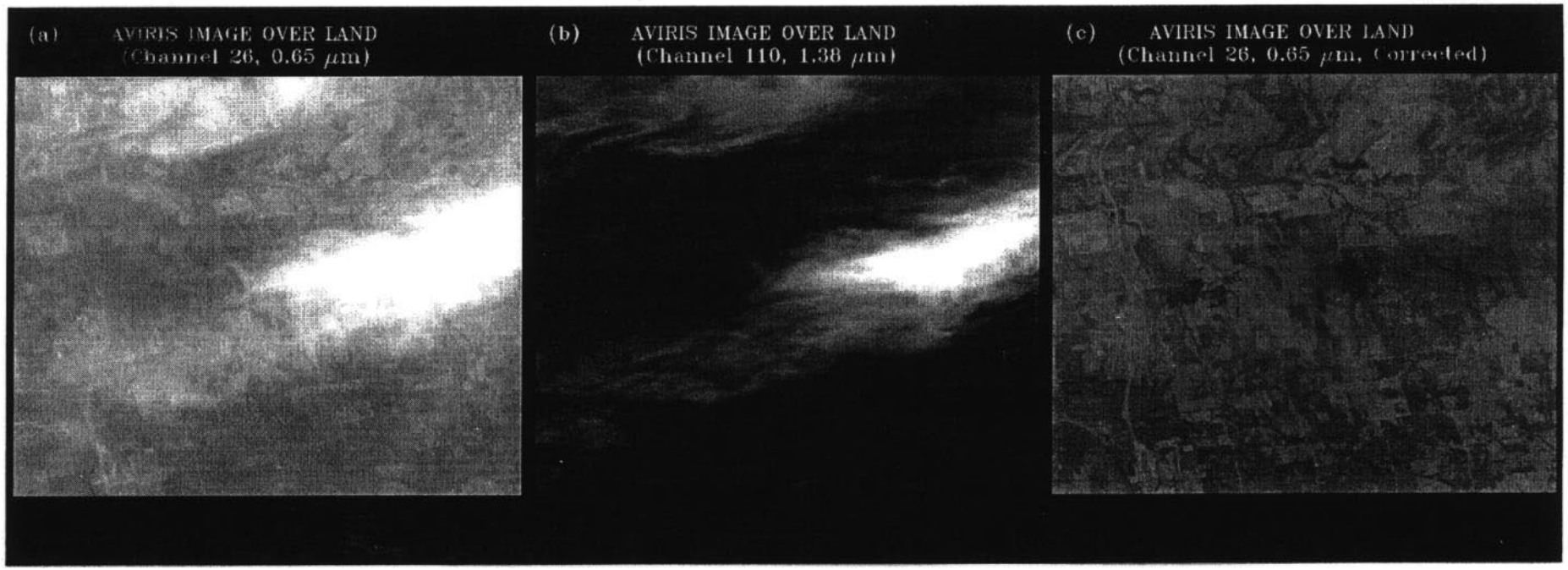



2.5×10^4
2.0×10^4
1.5×10^4
1.0×10^4
5.0×10^3
0
NUMBER OF PIXELS
3rd AVIRIS Overpass
2nd AVIRIS Overpass
0
0.01
0.02
0.03
0.04
0.05
APPARENT REFLECTANCE (1.38 MICRON)

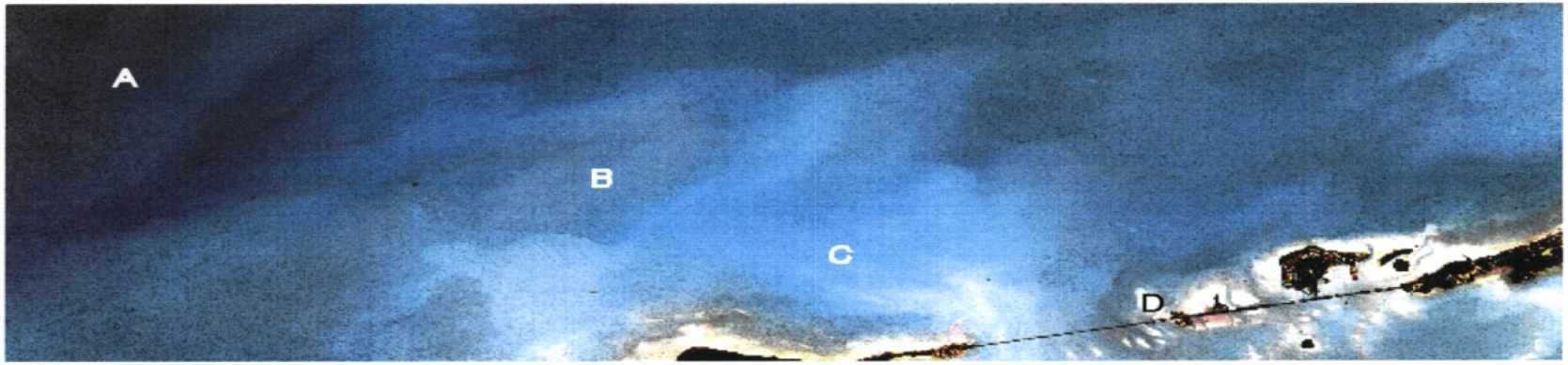

(A)
NDVI (UN−CORRECTED)
(3rd Pass, Palmdale, CA)
(B)
NDVI (CORRECTED)
(3rd Pass, Palmdale, CA)
(C)
NDVI (UN−CORRECTED)
(2nd Pass, Palmdale, CA)
(D)
NDVI (CORRECTED)
(2nd Pass, Palmdale, CA)
0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20


2500
2000
1500
1000
500
0
NUMBER OF PIXELS
Uncorrected, 3rd Pass
Uncorrected, 2nd Pass
(A)
0
0.05
0.10
0.15
0.20
0.25
NDVI

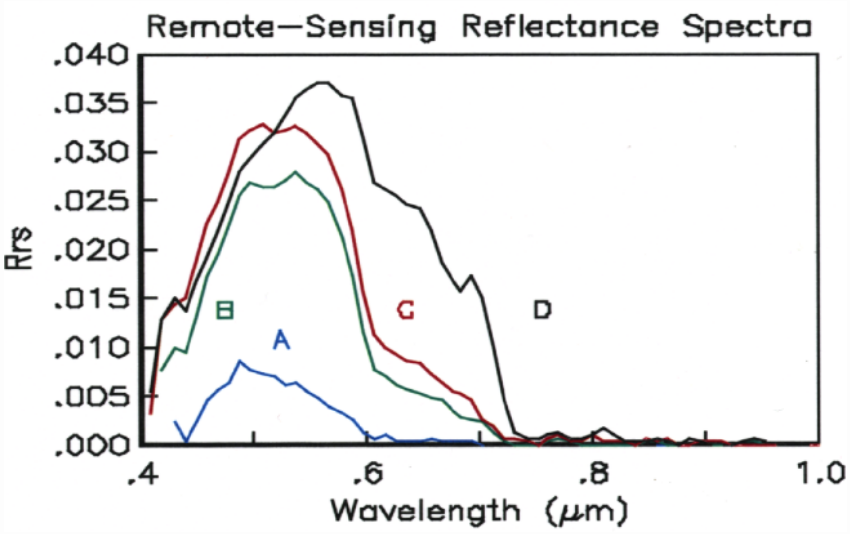

2500
2000
1500
1000
500
0
NUMBER OF PIXELS
Corrected, 3rd Pass
Corrected, 2nd Pass
(B)
0
0.05
0.10
0.15
0.20
0.25
NDVI


(a) AVIRIS IMAGE OVER LAND
(Channel 26, 0.65 μm)
(b) AVIRIS IMAGE OVER LAND
(Channel 110, 1.38 μm)
(c) AVIRIS IMAGE OVER LAND
(Channel 26, 0.65 μm, Corrected)

Ocean version of ATREM including surface glint correction



AVIRIS data were corrected using a new version of ATREM under development. This version is based on look-up tables which were calculated for different atmospheric and aerosol models, using full vector code. The application to data assumes that the reflectance at selected wavelengths greater than 1 micron will have 0 reflectance over water, even if it is shallow. Note how all the spectra go to 0 past 750 nm.



SUMMARY

- Thin-cirrus-contaminated images in the visible spectral region may appear perfectly clear. We have developed an empirical algorithm for removing/correcting thin cirrus effects in the 0.4-1.0 µm region using the 1.375-µm channel. Our applications of the algorithm to AVIRIS data show that the algorithm works properly.

- The 1.375-µm MODIS channel will have important applications for global observation of thin cirrus clouds, for atmospheric corrections of thin cirrus effects, and for improving remote sensing of land surfaces and ocean color.