Solar Irradiance Curves, Cirrus Contamination, and Sun Glint

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INTRODUCTION

- Solar irradiance curves – In the mid-1990s, we started to question the validity of the 1985 standard solar irradiance curve by C. Wehrli of World Radiation Center in Switzerland. A paper on the subject was published in 1996 (Applied Optics)

- Cirrus contamination – We began to address the cirrus detection and correction issue in early 1990s.

- Sun glint – By analyzing the AVIRIS data acquired over Salton Sea in California in the summer of 1988, we realized that the sunglint effects in the 0.4 – 2.5 micron wavelength range are spectrally flat, and the sunglint effects should, in principle, be correctable.

Relevant Equations and Definitions

In the absence of gas absorption, the radiance at the satellite level is:

$$L^*_{obs} = L^*_0 + L_g\, t'_u + L_w\, t_u, \quad (1)$$

L^*_0: path radiance; L_w: water leaving radiance;

L_g: radiance reflected at water surface; t'_u & t_u: *upward transmittances*

Multiply Eq. (1) by π and divide by ($\mu_0\, E_0$), Eq. (1) becomes:

$$\pi L_{obs} / (\mu_0\, E_0) = \pi L^*_0 / (\mu_0\, E_0) + \pi L_g\, t'_u\, [t_d / (\mu_0\, E_0\, t_d)\,] + \pi L_w\, t_u\, [t_d / (\mu_0\, E_0\, t_d)] \quad (2)$$

where E_0 = solar irr., μ_0 = cosine of solar zenith angle. We define:

Satellite apparent reflectance: $\rho^*_{obs} = \pi L_{obs} / (\mu_0\, E_0)$, (3)

$\rho^*_{atm} = \pi L^*_0 / (\mu_0\, E_0)$, (4)

Glint reflectance: $\rho_g = \pi L_g / (\mu_0\, E_0\, t_d)$ (5)

Water leaving reflectance: $\rho_w = \pi L_w / (\mu_0\, E_0\, t_d) = \pi L_w / E_d$ (6)

Remote sensing reflectance: $R_{rs} = \rho_w / \pi = L_w / E_d$ (6')

Substitute Eqs (3) – (6) into Eq. (2), we get:

$$\rho^*_{obs} = \rho^*_{atm} + \rho_g\, t_d\, t_u + \rho_w\, t_d\, t_u \quad (7)$$

After consideration of gas absorption and multiple reflection between the atmosphere and surface, & denoting $\rho^*_{atm+glint} = \rho^*_{atm} + \rho_g\, t_d\, t_u$, we can get:

$$\rho_w = (\rho^*_{obs}/T_g - \rho^*_{atm+glint}) / [t_d\, t_u + s\, (\rho^*_{obs}/T_g - \rho^*_{atm+glint})\,] \quad (8)$$

Gao, B.-C., M. J. Montes, Z. Ahmad, and C. O. Davis, Appl. Opt., 39, 887-896, February 2000.

Problems with the 1985 Wehrli Solar Irradiance Curve – Atmospheric water vapor contamination

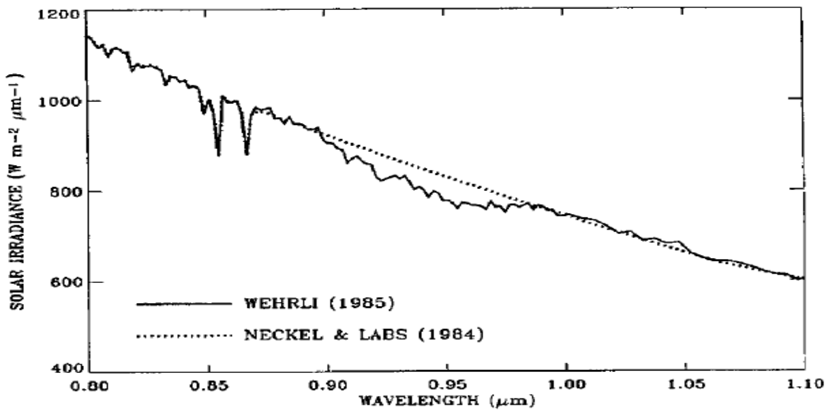

Fig. 8. Extraterrestrial solar irradiance curves from Wehrli[10] and from Neckel and Labs[7] between 0.8 and 1.1 μm.

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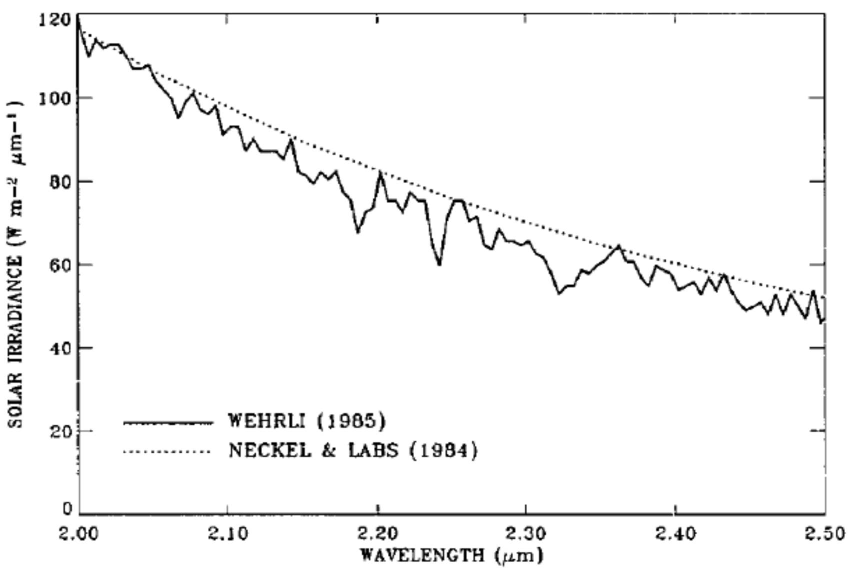


Fig. 1. Extraterrestrial solar irradiance curves between 2 and 2.5 μm from Wehrli[10] and from Neckel and Labs.[7]

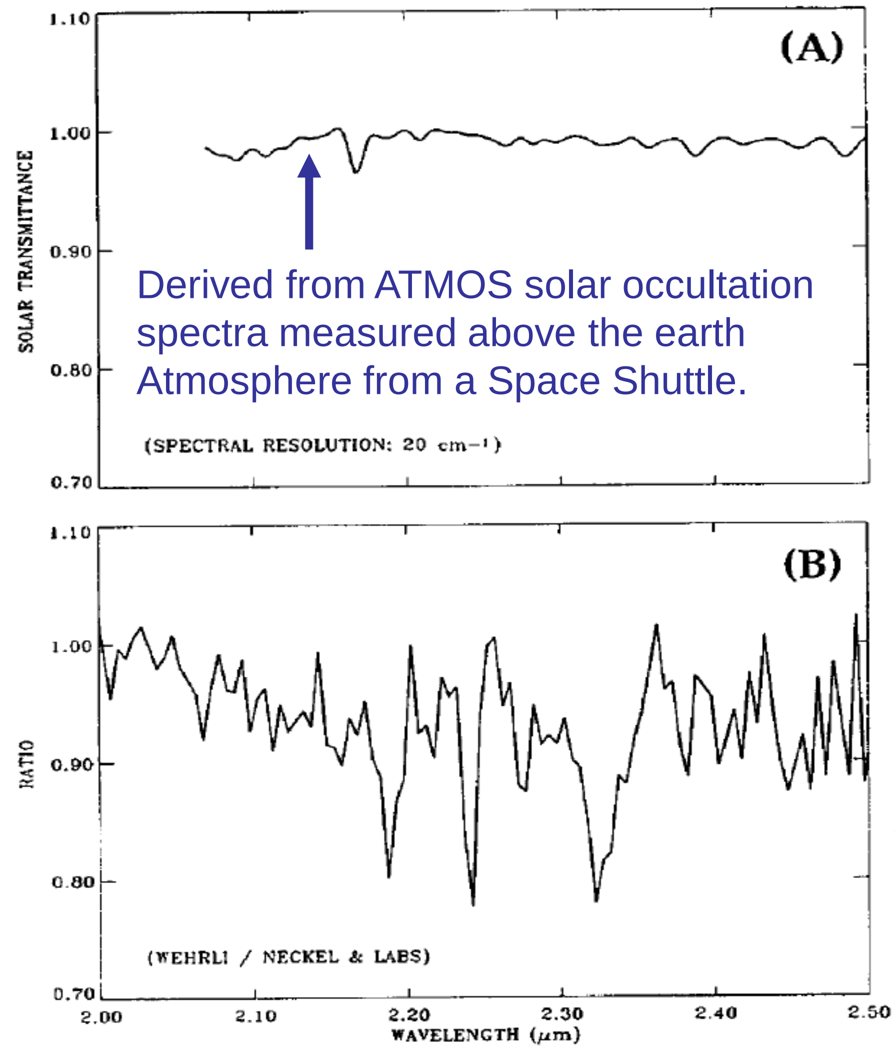


Fig. 4. (a) Solar transmittance spectrum at a resolution of 20 wave numbers, (b) ratio of the Wehrli[10] curve to the curve from Neckel and Labs[7] in Fig. 1.

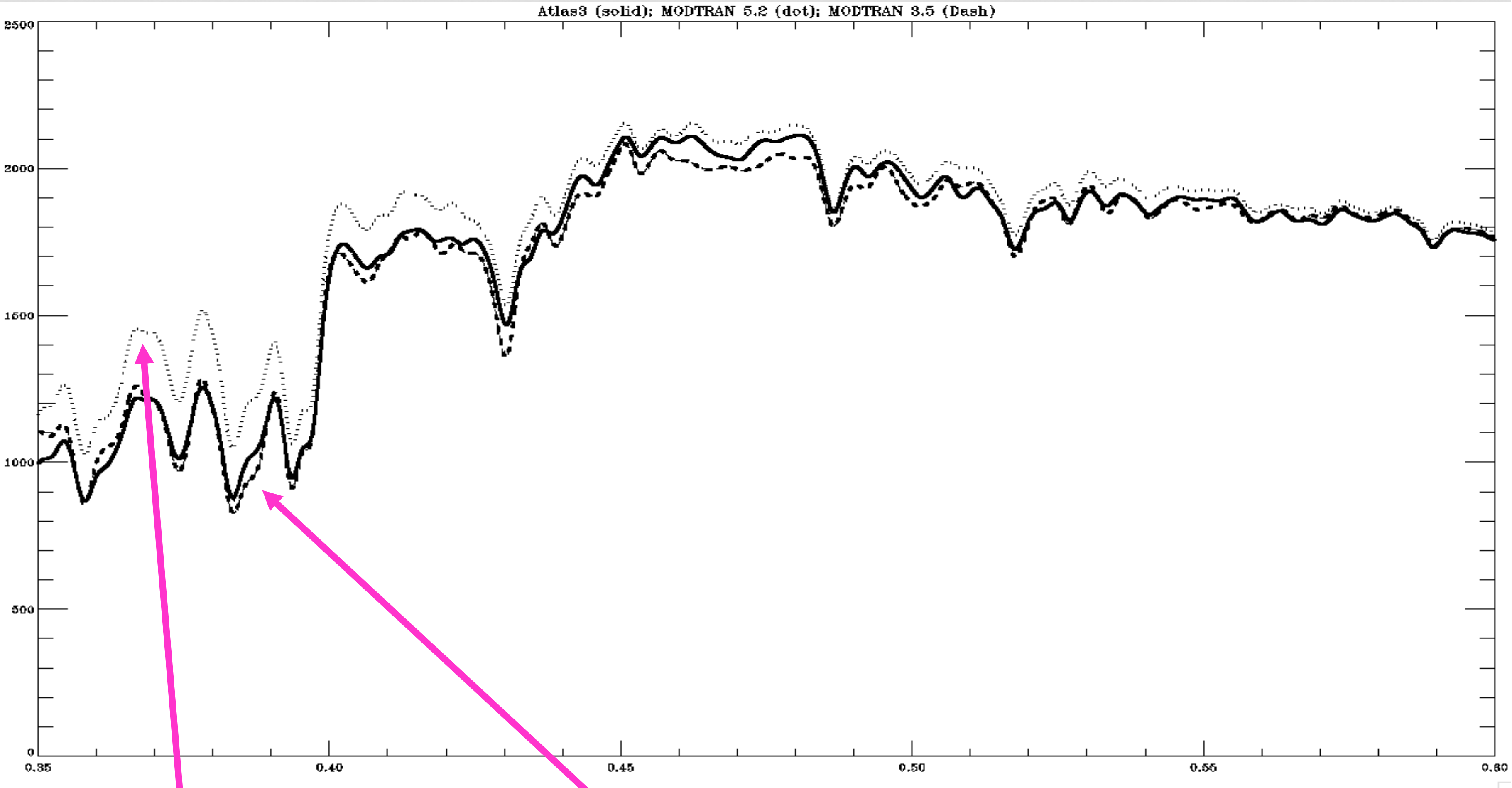
Recent Evaluation of Solar Irradiance Curves

- Judith Lean of NRL – the data set is not good because sampling spacing is too coarse.
- Fontenla 2011 - the standard solar irradiance curve adopted by the solar research community. It is not good for our use because the solar absorption features in the UV region are too deep.
- Neckel & Labs 2004 – The spectral resolution of this data set is poor, but the magnitude of solar irradiance values is quite reasonable.
- SORCE SSI – The data below 0.4 micron is fine. Above 0.4 micron, the spectral resolution is poor.
- Thuillier (SOLSTICE, 2003) – Steve Ungar provided the digital data. The data were already binned slightly.
- Thuillier (2004) ATLAS 1 & ATLAS 3 spectra – the two data sets differ in the far UV region, and they are the same in the 0.3 – 2.4 micron spectral range. No coverage above 2.4 micron.
- Kurucz data sets built in MODTRAN 3.5, Mod 4, and Mod 5.2 – The Kurucz Mod 5.2 solar IRR values below 0.5 micron are too large.

- We constructed another new solar curve for ATREM using Thuillier (2004) ATLAS 3 data below 644.7 nm & Kurucz 2005 Modtran 5.2 data above 644.7 nm.

Comparisons of three solar irradiance curves: Atlas3, MODTRAN 5.2, & MODTRAN 3.5

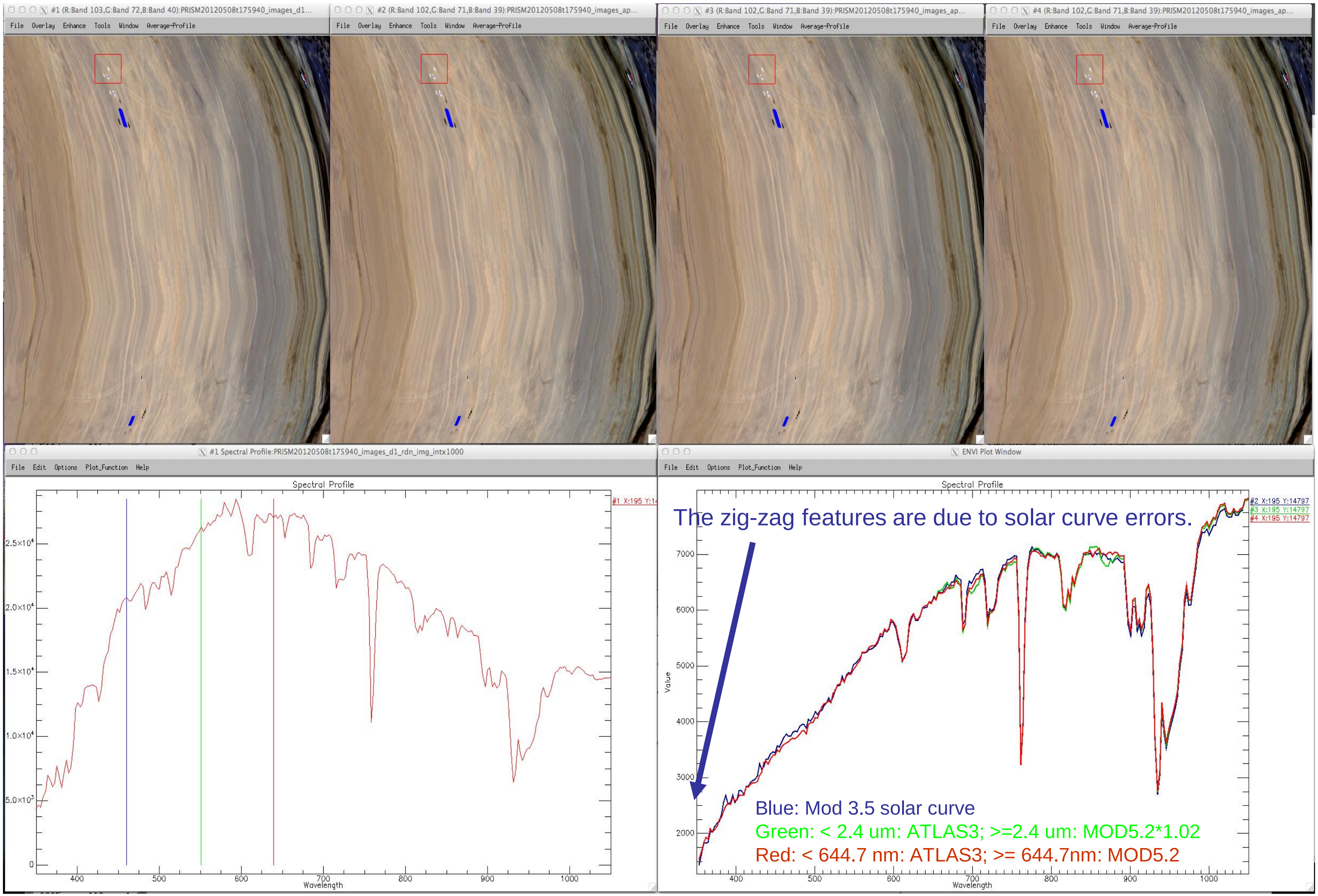
(The data were smoothed to 3 nm spectral resolution for comparison)



The magnitudes and spectral shapes are very different for the 3 standard solar irradiance curves in the 350 – 600 nm wavelength range.

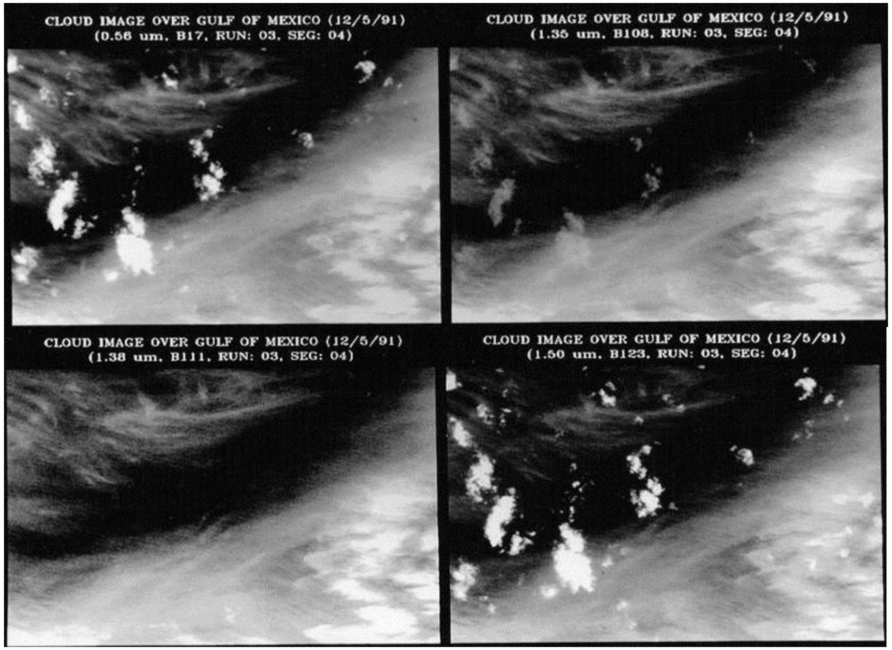
NASA JPL PRISM image acquired over Ivanpah, CA

(The lower right plot shows apparent reflectance spectra (π L / (μ_0 E_0) for 3 solar curves)

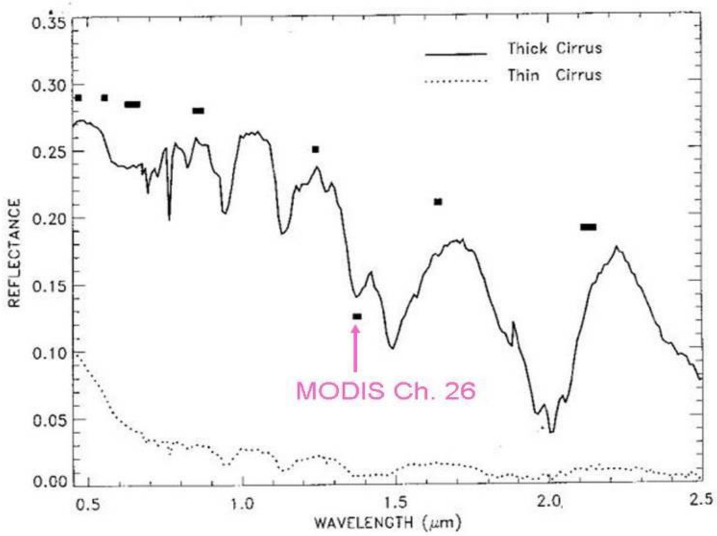


Cirrus Detection and Corrections

Sample AVIRIS Images

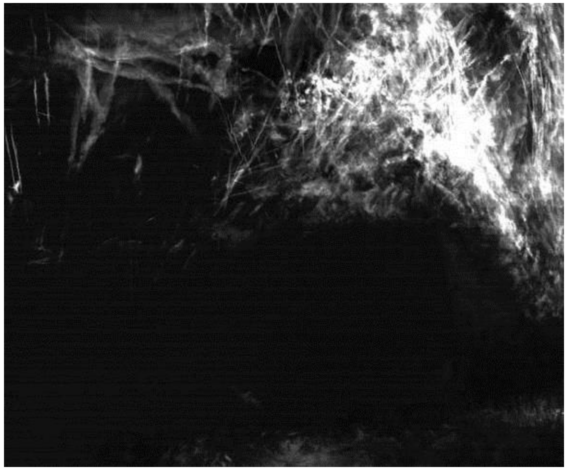


Sample AVIRIS Cirrus Spectra & MODIS Channels



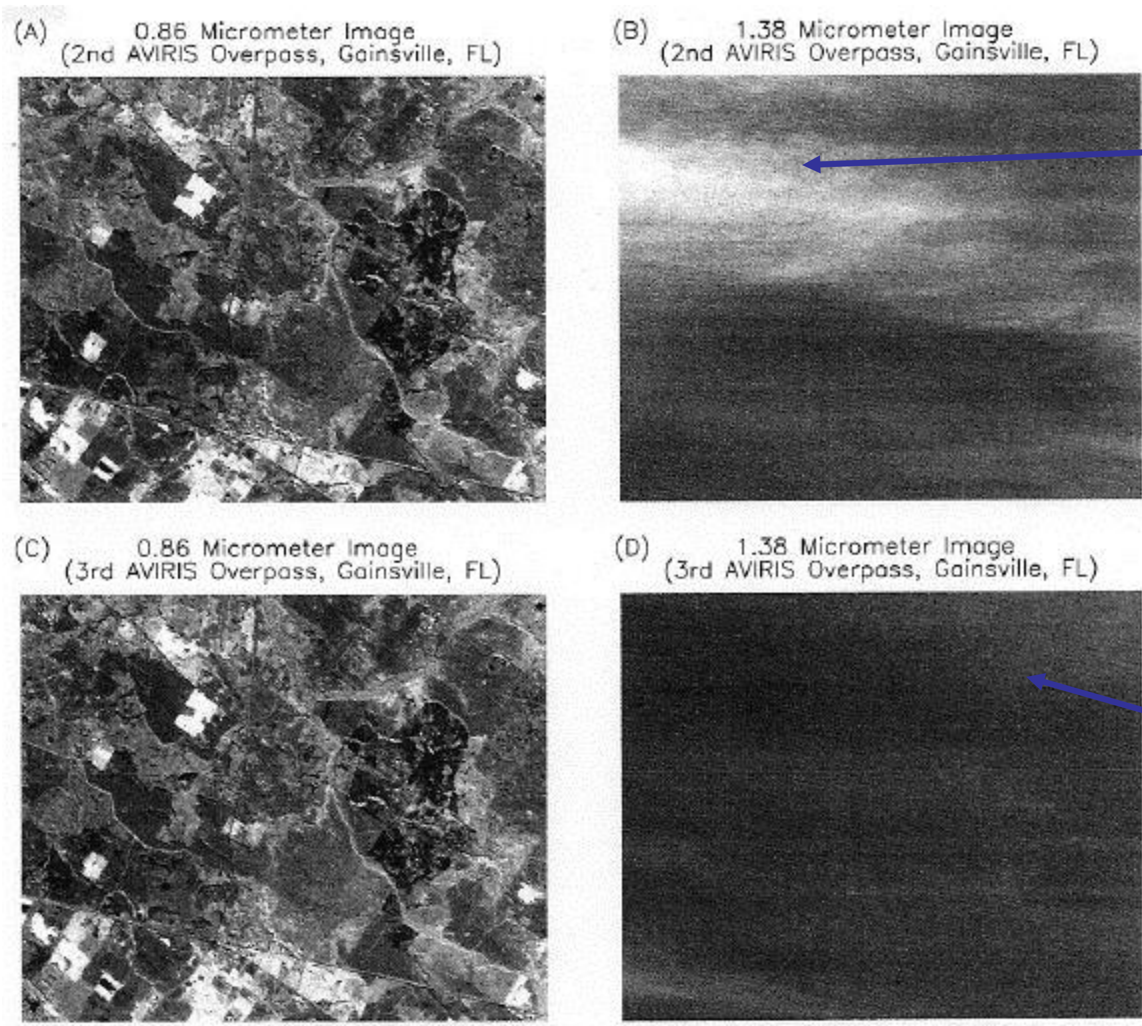
MODIS Original RGB Image

1.38-µm MODIS Image



Cirrus-Corrected RGB Image

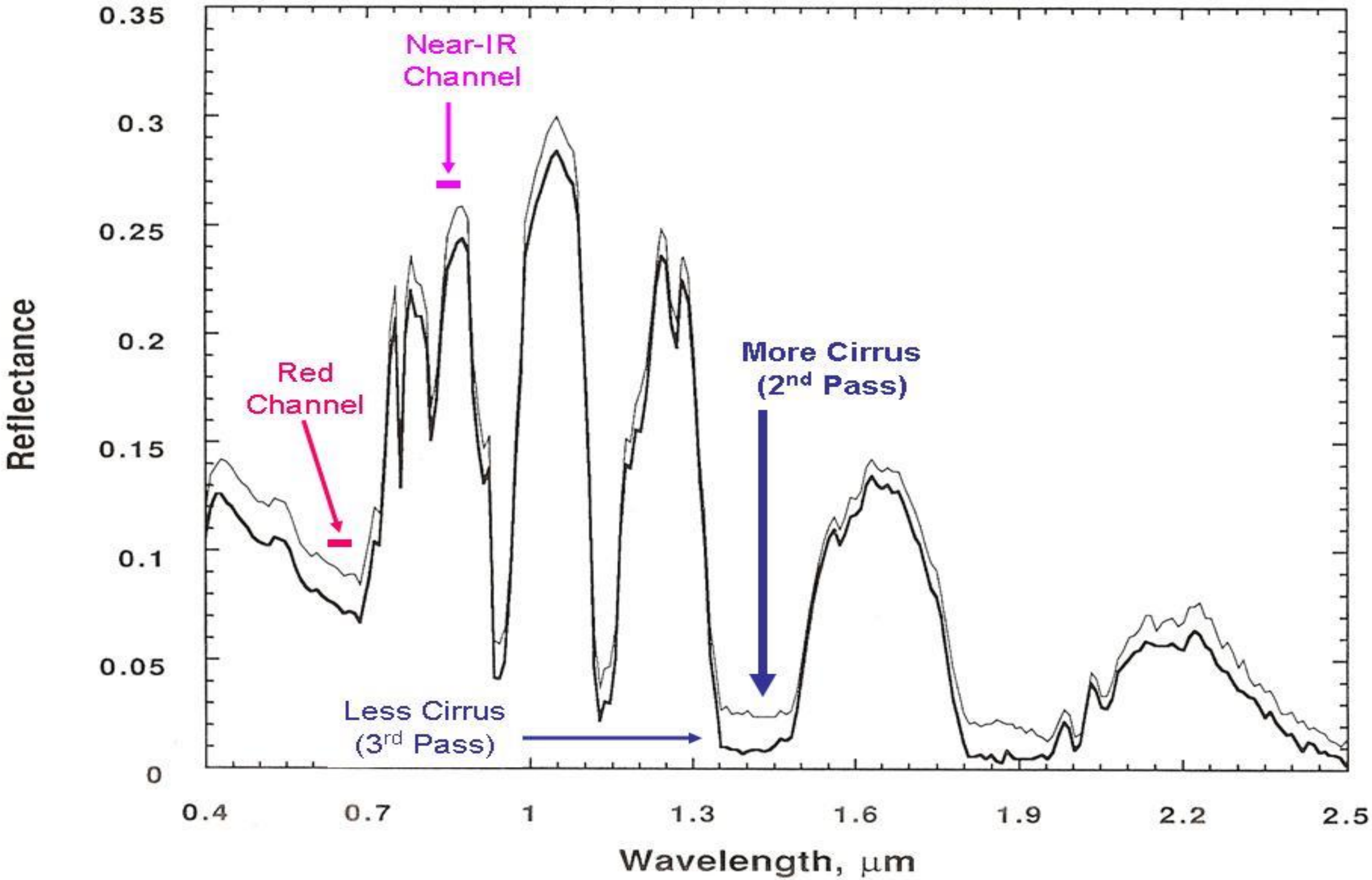
A pair of AVIRIS images acquired over Gainsville, Florida – with more cirrus (2nd pass) & less cirrus (3rd pass)



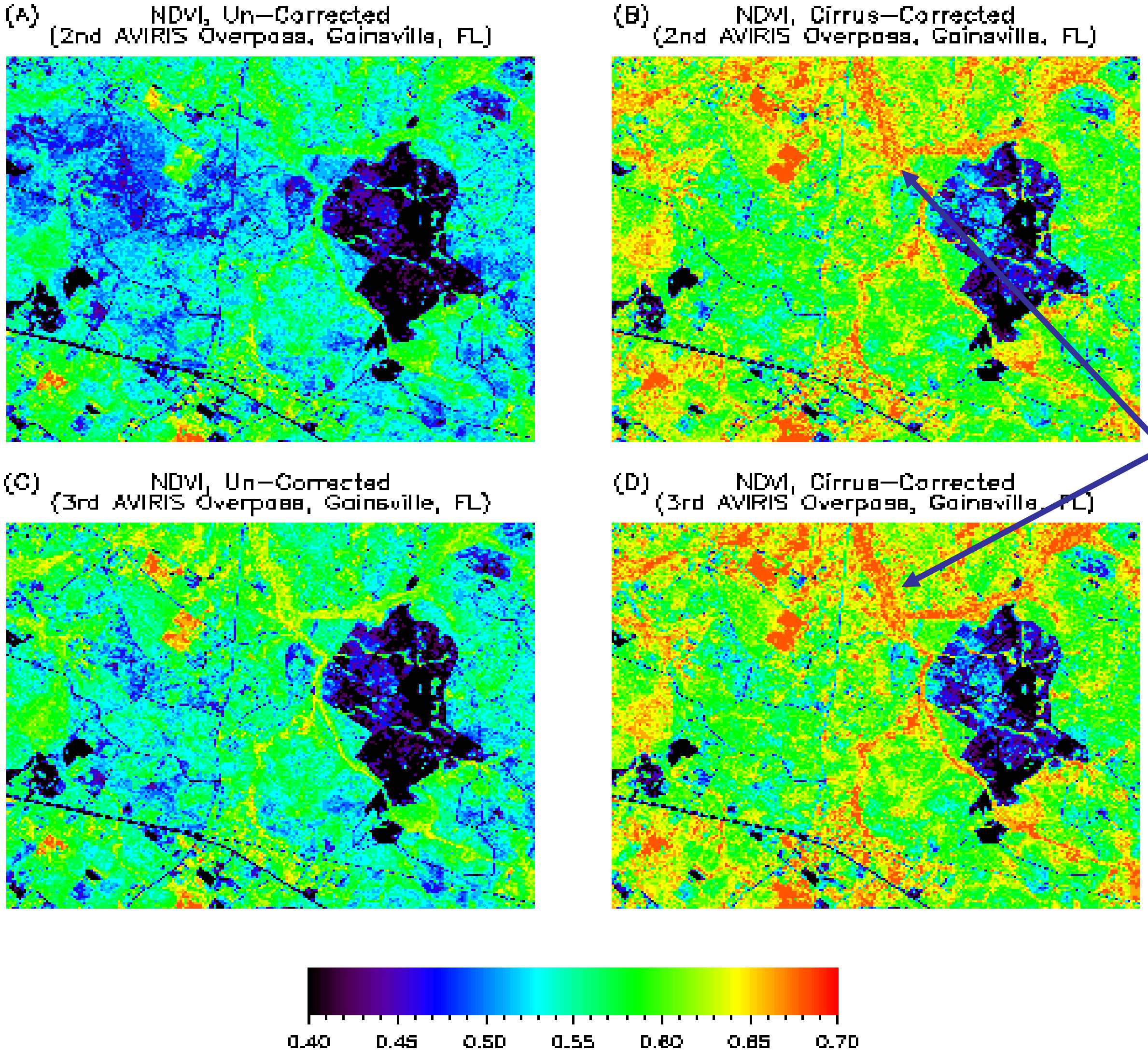
2nd pass, more cirrus

3rd pass, less cirrus

Cirrus-introduced additional radiances at the red (0.66 µm) and near-IR (0.86 µm) channels due to scattering of solar radiation

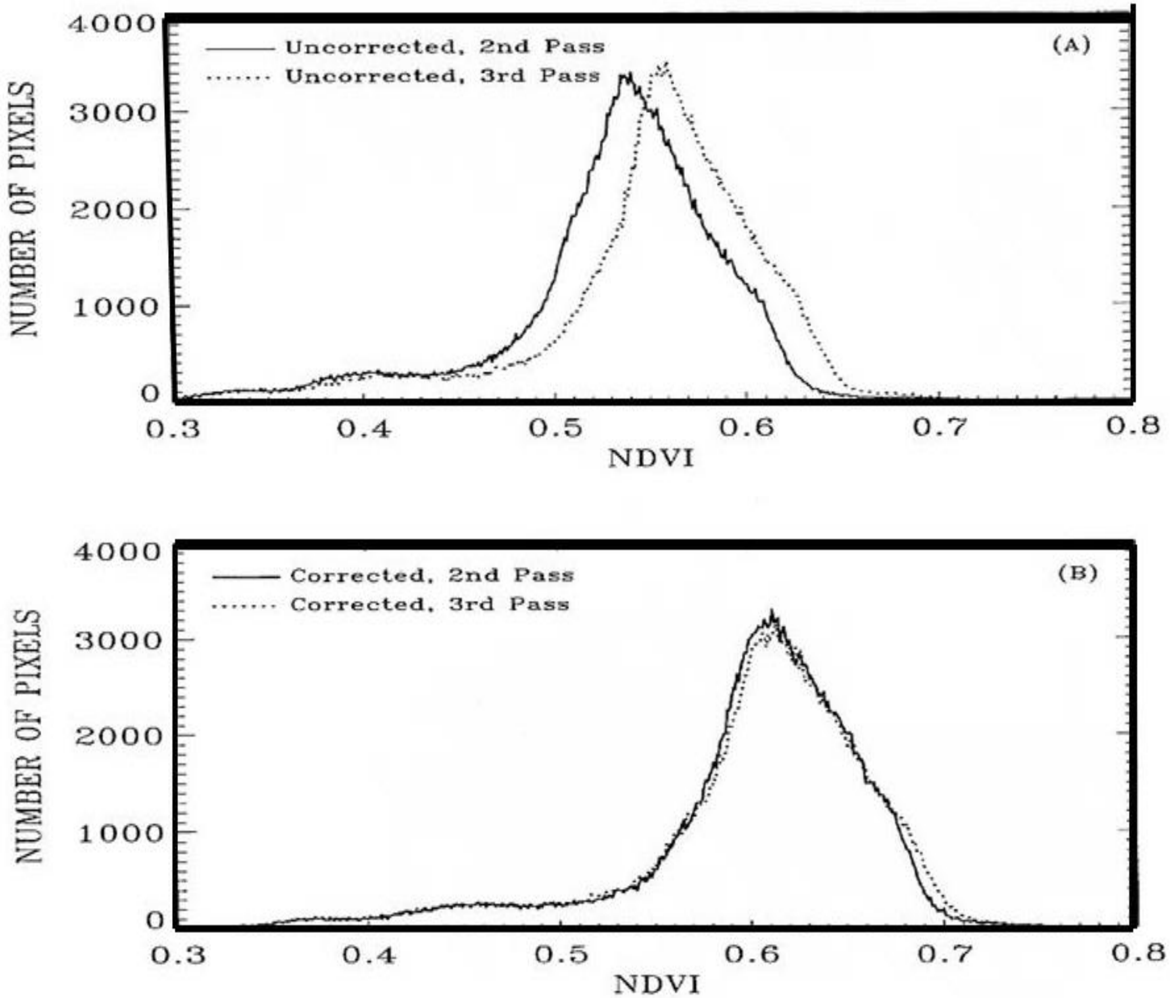


Un-corrected and Cirrus-corrected NDVI Images



After cirrus correction, the two NDVI images appear identical.

Histograms for the Un-corrected and Cirrus-corrected NDVI Images



Un-corrected

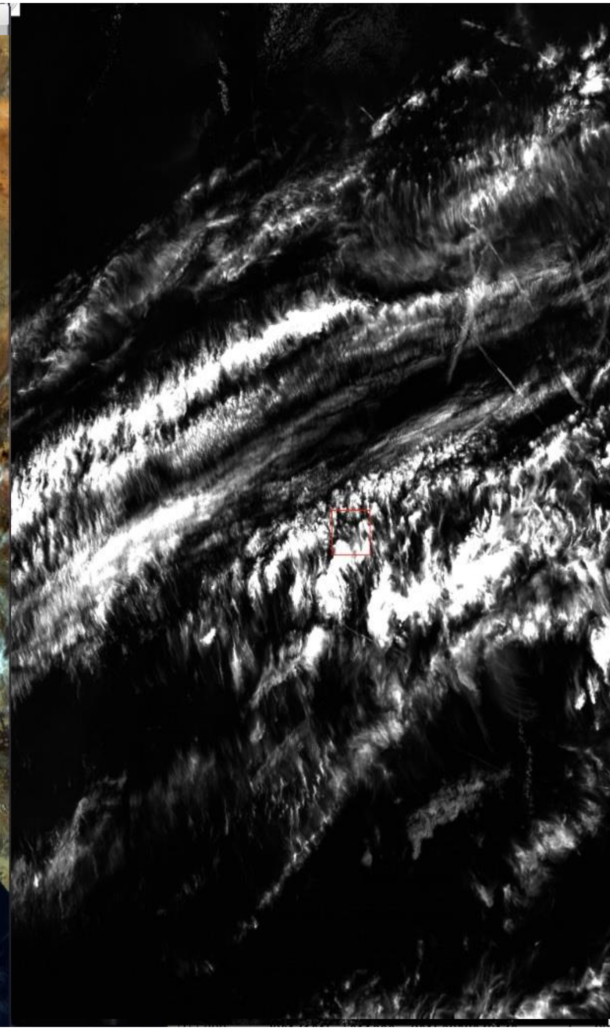
Cirrus-corrected

Figure 7. (A) Histograms of uncorrected NDVI images obtained from the second and the third pass AVIRIS data sets over Gainesville, Florida. (B) Similar to (A), except for cirrus-corrected NDVI images.

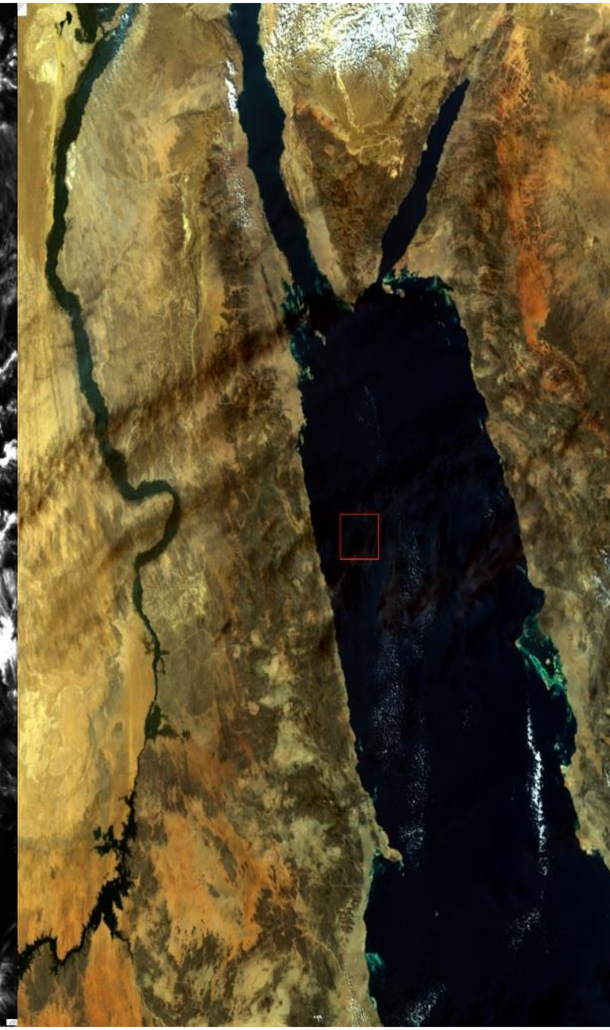
An Example of Cirrus Detection & Cirrus Removal Over Red Sea

VIIRS RGB Image

Cirrus Reflectance Image

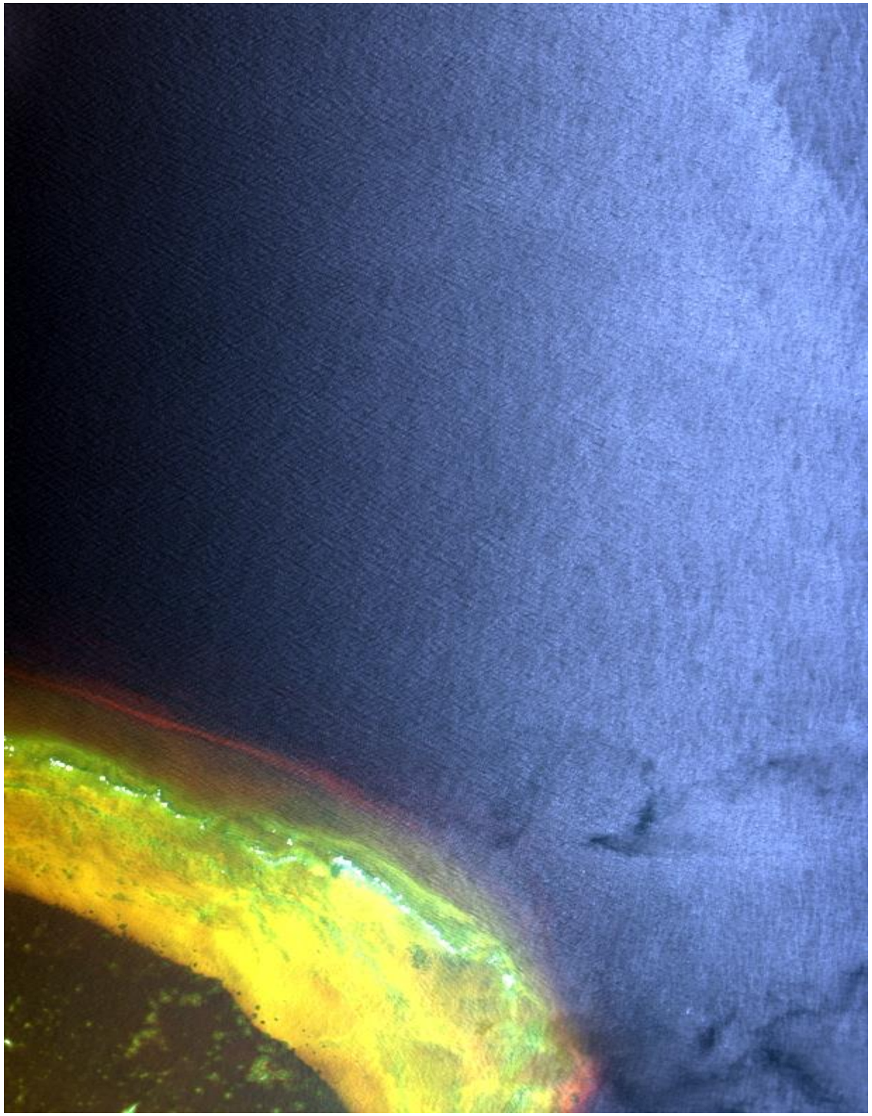


Cirrus-Removed RGB Image

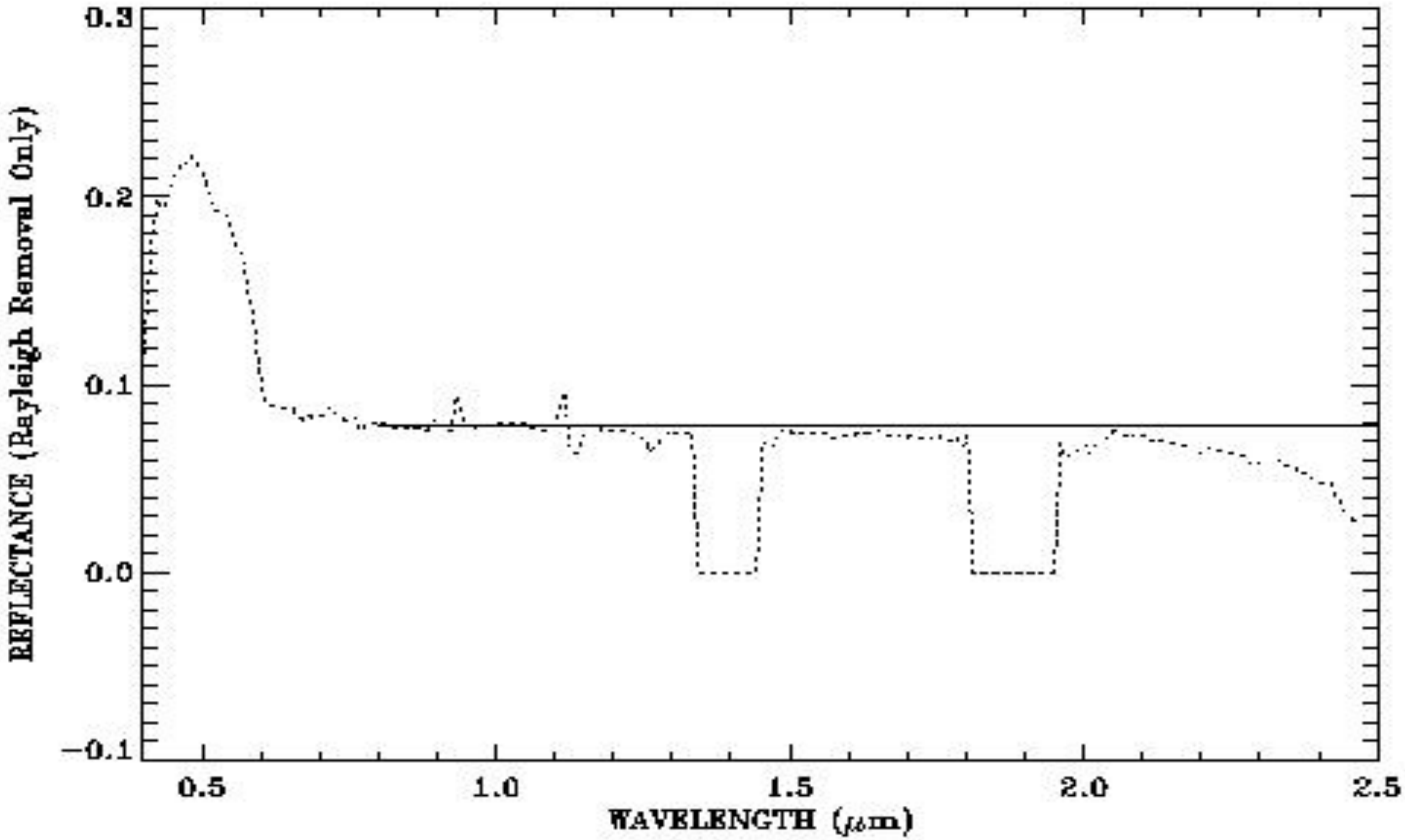


An AVIRIS Scene Over Hawaii Acquired in April 2000

Sunglint effect becomes stronger from left to right



The Reflectance Spectrum Obtained After Corrections Of Rayleigh Scattering and Gas Absorption Effects



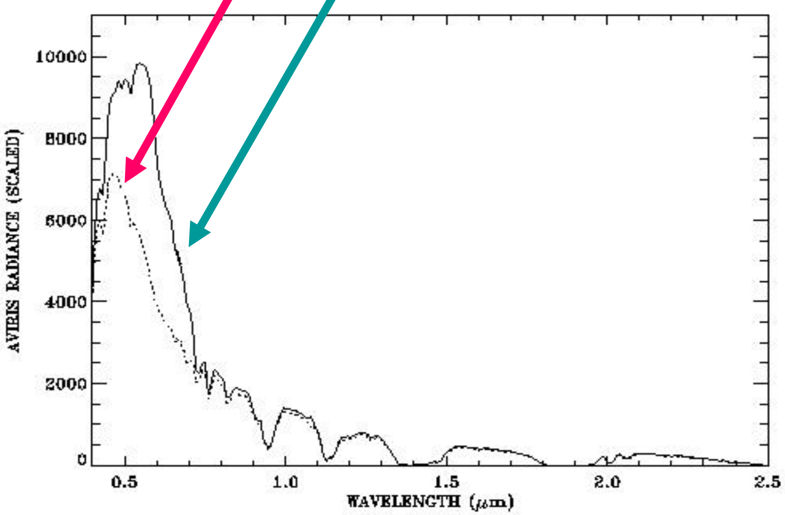
It is seen again that sunglint contributes a nearly constant reflectance value of ~ 8% above 0.8 μm.

A Case of Glint Removal Using AVIRIS Data Over Kaneohe Bay, HI

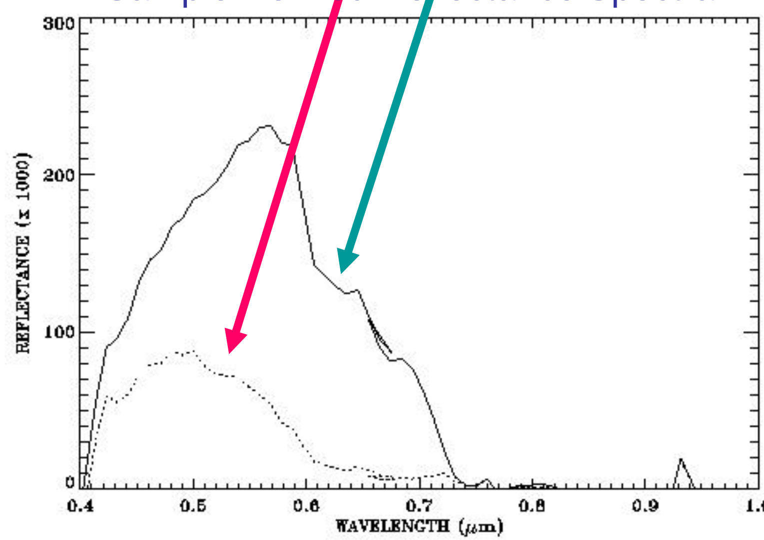
Before

After

Sample Radiance Spectra



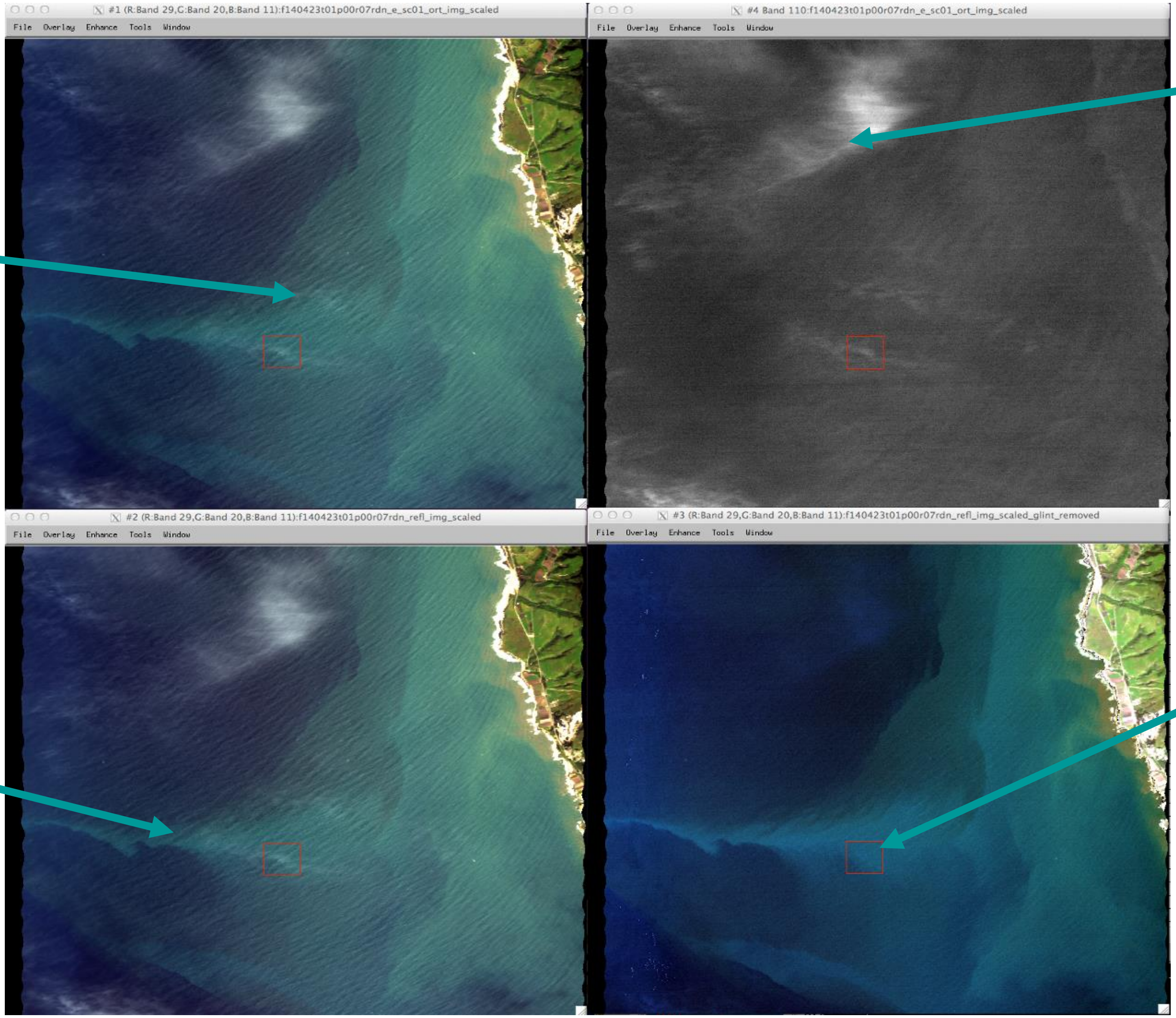
Sample Derived Reflectance Spectra



An example of cirrus & glint removal over waters using AVIRIS channels near 1240 nm (f140423t01p00r07rdn)

AVIRIS Radiance RGB Image

1.38-micron Cirrus image



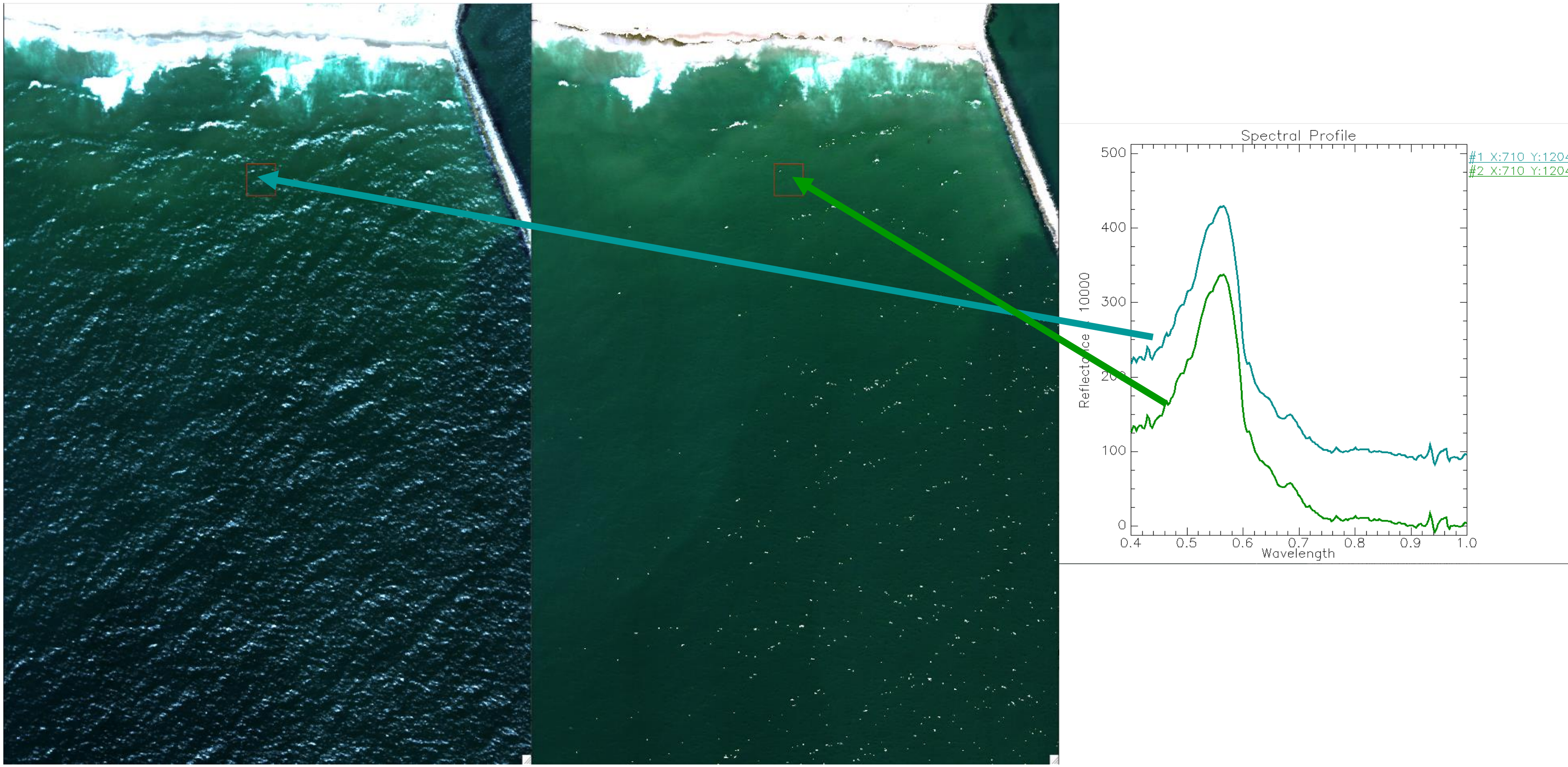
AVIRIS Reflectance RGB image

AVIRIS Reflectance RGB image after cirrus + glint correction using channels near 1.24 micron.

Most cirrus features over water surfaces are removed after such an empirical correction.

An example of glint removal from the JPL PRISM data

Before Glint Removal After Glint Removal



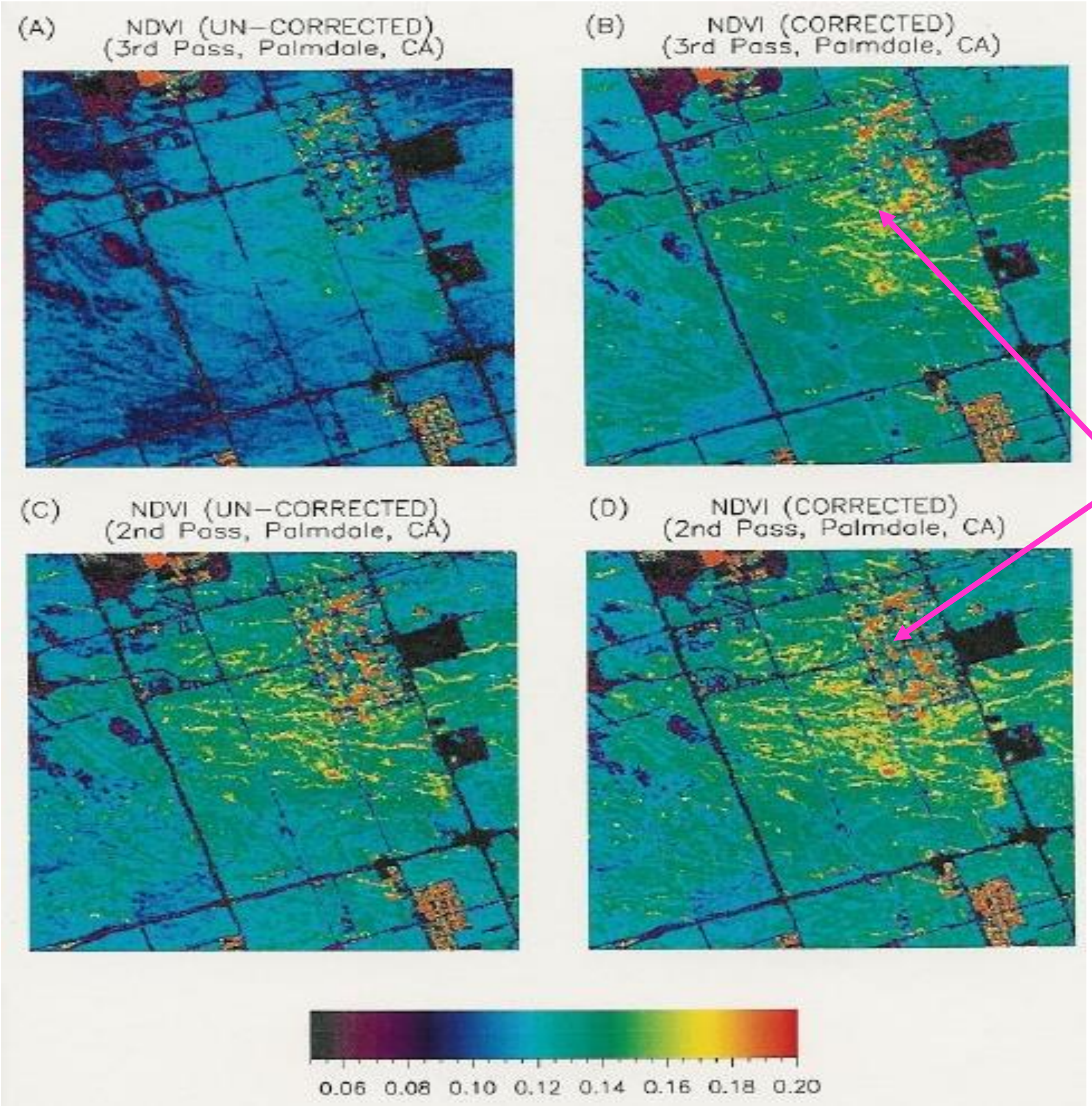
SUMMARY

- In this presentation, I have covered three topics – solar irradiance curves, cirrus detection and corrections, and empirical glint removal.

- For proper retrieval of land surface reflectances and water leaving reflectances from hyperspectral imaging data, we still need an improved solar irradiance curve.

- So far, the empirical techniques presented here for removing thin cirrus and sunglint effects have not been used in operational codes. Improvements in treating the downward and upward atmospheric transmittance terms are still needed.

Un-corrected and Cirrus-corrected NDVI Images



After cirrus correction, the two NDVI images appear identical.

Second Case of Glint Removal Using AVIRIS Data Over Pearl Harbor, HI

Before

After