AIRS infrared polarization sensitivity and in-flight observations

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ABSTRACT

The Atmospheric Infrared Sounder (AIRS) is a space-based instrument that measures the upwelling atmospheric spectrum in the infrared. AIRS is one of several instruments on the EOS-Aqua spacecraft launched on May 4, 2002. Typically, instrument polarization is not a concern in the infrared because the scene is usually not significantly polarized. A small amount of polarization is expected over ocean, which can be seen in the AIRS 3.7 µm window channels. The polarization is seen as a signal difference between two channels with the same center frequency but different polarizations. The observations are compared to a model that relies on measurements of instrument polarization made pre-flight. A first look at a comparison of the observations of sea surface polarization to expectations is presented.

Keywords: AIRS, Atmosphere, Ocean Polarization, Infrared, Polarization

1. INTRODUCTION

The AIRS has a pair of channels which are particularly well suited to measuring polarization. The channels have the same center frequency, but lie in different orders of the grating and on different detector arrays. Because of their differing optical nature, their polarization is different. The channels combined are suitable for detecting polarization of the scene.

Polarization of the emitted radiance of the ocean surface is expected for large viewing angles. A model for the polarization-dependent emissivity developed by Shaw, et. al. (ref 1) was used to predict the signal expected from the AIRS when viewing ocean surfaces.

2. THEORY

Assuming the scan mirror polarization is zero (this is close to the case for the shortwave channels used in the modeling, see below), the signal expected from a polarized scene can be found from the Mueller Matrix Equation (reference 2).

$$S = M_{sp} N_{sc}$$

The scene polarization is rotated by the scan mirror, giving the scene polarization stokes vector.

$$N_{sc} = \frac{1}{2} P_{sc} \begin{bmatrix} \varepsilon_s(\theta) + \varepsilon_p(\theta) \\ \left[\varepsilon_s(\theta) - \varepsilon_p(\theta)\right]\cos 2\theta \\ \left[\varepsilon_s(\theta) + \varepsilon_p(\theta)\right]\sin 2\theta \\ 0 \end{bmatrix}$$

Where ε is the ocean surface smissivity, and θ is the angle relative to the AIRS, or the scan angle; AIRS produces an image rotation with scan angle that is equal to the scan angle. P_{sc} is the Planck Blackbody radiance evaluated at the temperature of the scene The spectrometer Mueller Matrix is

$$M_{sp} = \frac{1}{2}\begin{bmatrix} q+r & (q-r)\cos 2\delta & (q-r)\sin 2\delta & 0 \\ (q-r)\cos 2\delta & (q+r)\cos^2 2\delta + 2\sqrt{(qr)}\sin^2 2\delta & \left(q+r-2\sqrt{(qr)}\sin 2\delta\cos 2\delta\right) & 0 \\ (q-r)\sin 2\delta & \left(q+r-2\sqrt{(qr)}\right)\sin 2\delta\cos 2\delta & (q+r)\sin^2 2\delta + 2\sqrt{(qr)}\cos^2 2\delta & 0 \\ 0 & 0 & 0 & 2\sqrt{(qr)} \end{bmatrix}$$

where q, and r are the transmission of the spectrometer in the s and p axes, and δ is the orientation. First we define the polarization terms,

$$p_K = \frac{\varepsilon_s - \varepsilon_p}{\varepsilon_s + \varepsilon_p} \qquad \text{and} \qquad p_t = \frac{q-r}{q+r}$$

The signal on a detector is the first term in the Mueller Matrix Product. Substitution gives,

$$S = S_{sc} - S_{sv} = N_{sc}KT\{1 + p_K p_t \cos 2(\theta\text{-}\delta)\}$$

where

$$K = \frac{\varepsilon_s + \varepsilon_p}{2} \qquad \text{and} \qquad T = \frac{q+r}{2} = 1$$

and S is the signal radiance at the sensor aperture from the scene "sc", and from the space view "sv" respectively. We have set the transmission of the system, T, to equal 1 because we are not interested in the absolute signal for this exercise, but the dependence of the difference of the signal between two channels on scan angle The first part of the equation is the unpolarized signal. The second part is what is expected due to a polarized scene. The signal difference expected from the two overlap channels due to a polarized scene expressed as a temperature error is

$$T_{err} = \frac{S_1 - S_2}{\partial N_{sc}/\partial T}$$

where ∂Nsc/∂T is the partial derivative of the scene radiance with respect to temperature.

3. SCENE POLARIZATION

Figure 1 shows the polarization of the ocean emissivity as obtained from reference 1. Note that the "P" component is parallel to the plane of incidence, or in the "scan" direction, while the "S" component is in the "track" direction. This orientation is 90° relative to the AIRS measured polarization. Figure 2 shows the first and second terms in the Stokes vector for the scene. The top of Figure 2 shows the first term, which represents the unpolarized emission. There is a roll-off in the emission at high zenith angles, which should cause a reduction in the signal assuming no reflected contribution. The second term in the Stokes vector represents the product of the scene polarization and the rotation of the orientation as viewed by AIRS. The ocean polarization increases with scan angle, but the cos2θ, from the rotation of the polarization axis of the spectrometer due to scanning causes a dampening, that takes over from about 35 deg to the end of scan.

4. AIRS POLARIZATION DATA

Figure 3 shows the AIRS measured polarization in the 3.5 to 4.7 micron region. The AIRS polarization varies from one module to the next because of the different grating orders used in the spectral separation and the field location on the focal plane. The AIRS Focal Plane Layout is shown in Figure 4. Detectors were placed to allow spectral overlap between two spectrally adjacent modules; the unexpected benefit for polarization sensing was the differing polarization of the overlapping channels.

Channels 2252 (2561 cm^{-1}) and 2280 (2561 cm^{-1}) were chosen (table 1) because they have a good match in frequency, with highly different polarization states. Another overlap region exists in the longwave, but the match is not as good, and the scan mirror polarization is not negligible.

Channel	2252	2280
Wavelength (microns)	3.9051	3.9045
Wavenumber (cm^{-1})	2560.8	2561.1
Scan Mirror Polarization	0.0031	0.0031
AIRS Polarization	0.1398	0.0200
AIRS Phase (deg)	-7.76	-43.2

Table 1. Properties of the two channels used to sense ocean polarization

The phase of the polarization for AIRS is shown in Figure 5. The phases were measured relative to the scan direction. The "S" plane for AIRS is in the scan direction, so the phases must be rotated by 90° to be in the same coordinate system as the scene polarization.

5. POLARIZATION SIGNAL

Substitution of the scene polarization terms and the AIRS polarization terms gives the signal vs. scan angle expressed in terms of solar zenith angle we can expect due to the ocean polarization. Figure 6 shows the expected signal for the overlap channels. The channels have roughly the same overall response, but a slight difference exists, particularly at the end of scans. This difference is due to the polarization coupling of the scene and the AIRS.

Figure 7 shows the difference in signal between the overlap channels expressed in terms of a temperature change at 285K. The asymmetry is clearly visible and due solely to the non-zero phase of the AIRS spectrometer. An offset of -0.08K is applied to the modeled difference and is very likely due to the basic transmission difference, T, between the channels. It may also be a radiometric calibration error between the two channels. The value is within the expected calibration uncertainty (reference 2). Figure 7 also shows the observed difference of the two channels when viewing clear ocean scenes collected for the entire month of Oct, 2003 (about 250,000 footprints each day (*) and night (^). Day and Night results are shown separately to illustrate the stability of the result. Reasonable agreement suggests the asymmetric signal seen is indeed a polarization coupling of the AIRS with the scene. The small amplitude of the effect makes it hard to improve upon the agreement without better knowledge of the AIRS polarization amplitude and phase. The overlap channels also have different 2D spatial response and are very sensitive to non-homogeneous scenes. The polarization sensing only works if the scene is uniform.

6. SUMMARY AND CONCLUSIONS

A technique using two channels of differing polarization but equal spectral response has demonstrated the ability to detect the polarization of the emitted signal from the ocean at high scan angles. The signal is extremely small and may not be useful for detection of infrared scene polarization on a sample-by-sample basis. Infrared scene polarization (such as over oceans) may have an impact on the radiometry. It is not recommended that we correct the polarization effects at this time since the effect is less than the 0.1K, and much smaller than this for satellite zenith angles less than ±30°.

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REFERENCES

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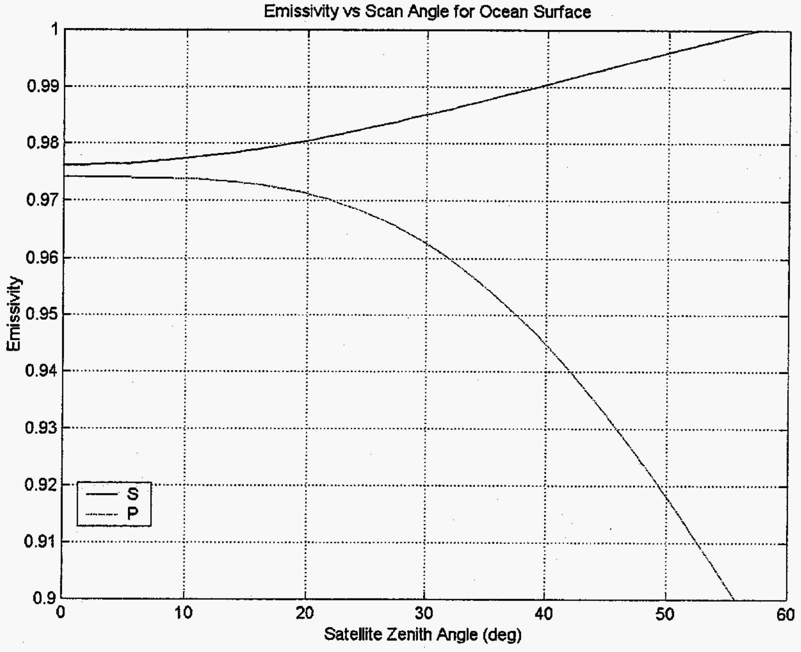

Figure 1. Emissivity model for the ocean surface is taken from reference 1.

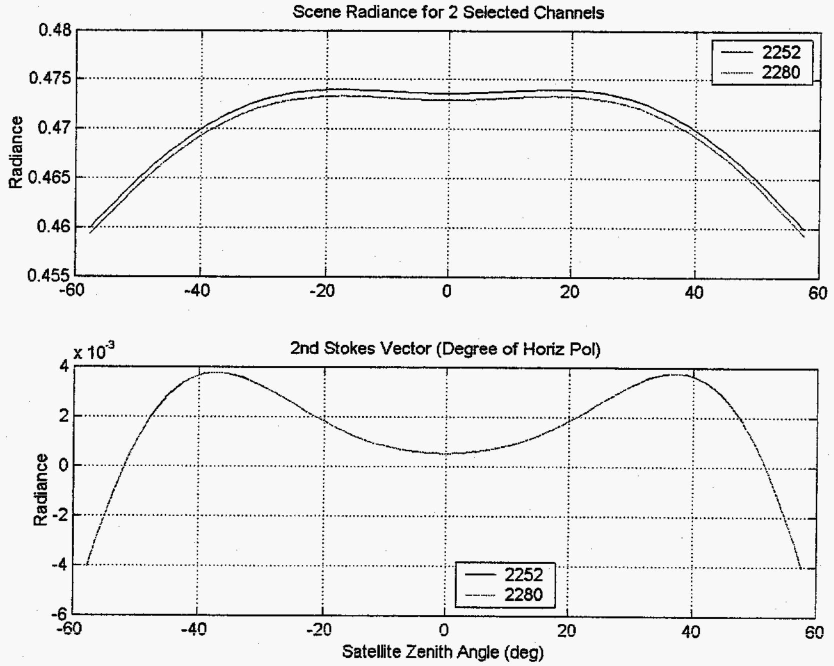

Figure 2. (Top) First term in stokes vector for the scene represents unpolarized signal. We see roll-off due to bulk emissivity drop near end of scan. (Bottom) Second term in stokes vector represents the degree of horizontal polarization of the scene.

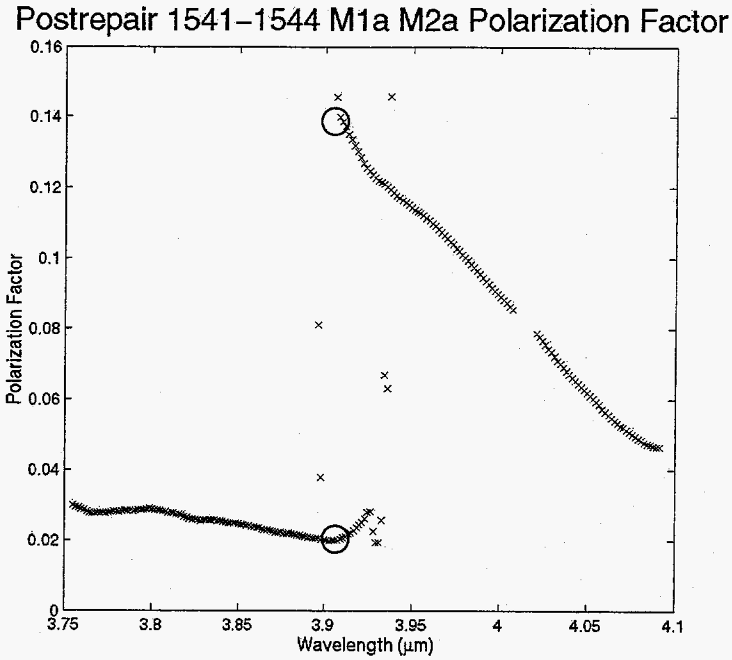

Figure 3. AIRS Polarization in the shortwave channels. Circles at 3.9 microns show data used for this analysis.

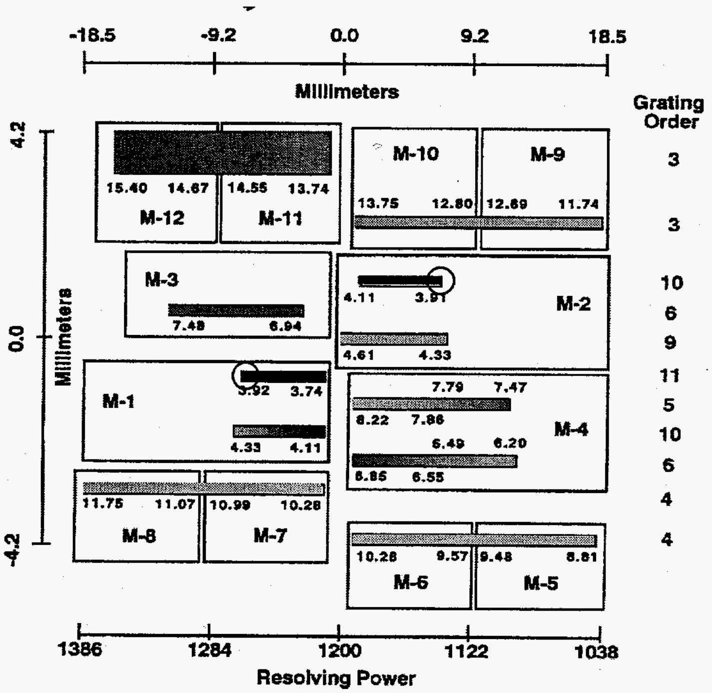

Figure 4. AIRS Focal Plane Assembly. Layout shows grating orders and locations of channels used in the polarization measurement.

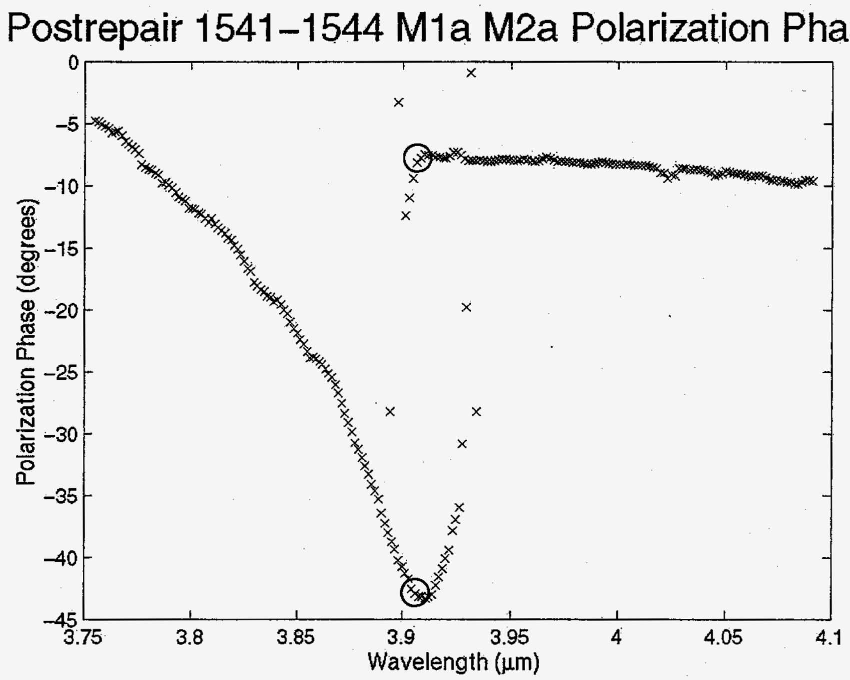

Figure 5. AIRS Measured Phase in the shortwave channels relative to the scan direction

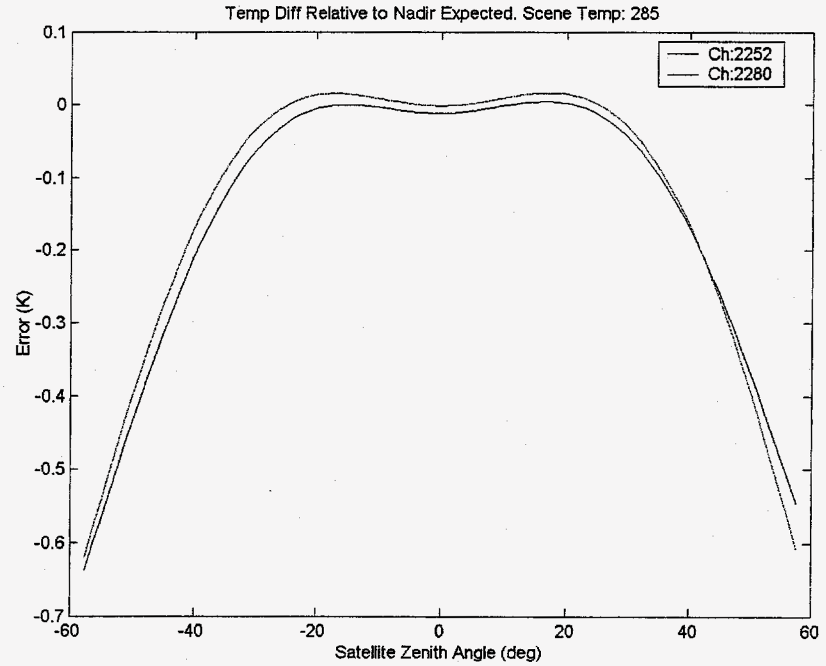

Figure 6. Expected signal from the overlap channels

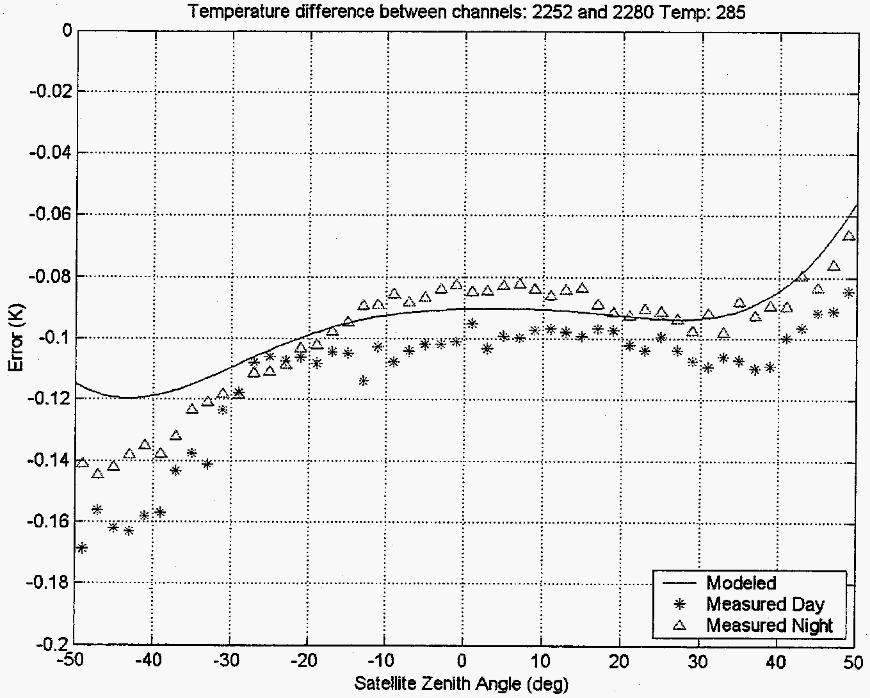

Figure 7. Expected (modeled) difference between the two overlap channels compared to global observations of clear ocean scenes. Modeled data is offset by –0.08 degrees.