P 5.4

VEGETATION MONITORING AND THIN CIRRUS DETECTION ON THE NEXT GENERATION GOES IMAGER

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1. INTRODUCTION

The Advanced Baseline Imager (ABI) will be the next generation imager on the Geostationary Operational Environmental Satellite (GOES-R) beginning in approximately 2012. The ABI will expand the GOES imagers from five channels up to 12 to 18 channels (pending final spectral configuration selection). Of the proposed 18 channels, seven will be in the visible and near infrared (NIR). A NIR channel at 0.86 µm will be used to monitor vegetation trends. Another new channel at 1.38 µm will detect very thin, daytime cirrus clouds. This channel is centered in a strong water vapor absorption spectral region so that surface or lower troposphere cloud reflection is attenuated (for most atmospheres). Determining a center wavelength and bandwidth for each of the visible and near IR channels has been done using various Airborne Visible InfraRed Imaging Spectrometer (AVIRIS) data scenes along with reviewing spectral characteristics of other existing and planned instruments. AVIRIS data were chosen for its very high spectral resolution. AVIRIS data contains 224 channels between 0.4 µm and 2.5 µm (Vane, 1987). AVIRIS data scenes include a river valley in the tropics, a forest fire over California and a multiple layer (cirrus/cumulus) cloud scene. These scenes were made available at the Second NOAA Hyper-spectral Meeting.

The procedures and results of using AVIRIS data to determine ideal center wavelengths and bandwidths for the 0.86 µm and 1.38 µm channels are described in detail in the following two sections. Just as important as determining proper center wavelength and bandwidth for each channel, it is important to assess the impact of radiation detection from outside the specified bandwidth (out-of-channel radiation). Section four describes the effects of out-of-channel radiation in the 0.86 µm and 1.38 µm channels. Section five demonstrates the influence of total precipitable water on solar transmittance for the selected spectral characteristics of the 1.38 µm channel.

2. 0.86 µm CHANNEL

From current and other proposed instruments, such as the MODerate resolution Imaging Spectroradiometer (MODIS) and the Advanced Very High Resolution Radiometer (AVHRR) it is known that a channel near 0.86 µm, in conjunction with the 0.64 µm channel, is useful to monitor vegetation trends. As shown in figure 1 a major advantage of using the 0.86 µm channel is that radiation is strongly reflected by areas of heavy vegetation, opposed to areas of light vegetation.

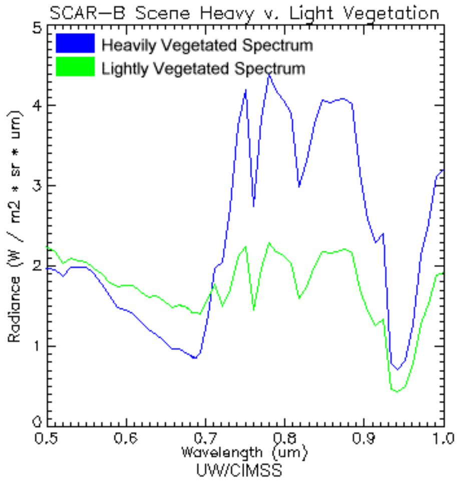

Fig. 1: AVIRIS SCAR-B Wavelength v. Radiance. The blue line represents an area of heavy vegetation and the green line represents an area of lighter vegetation. Notice the increased contrast over the area with heavy vegetation.

For the 0.86 µm channel evaluation, a tropical river valley scene collected during the SCAR-B field program (i.e. the SCAR-B scene) and a forest fire scene in California (i.e. the Linden scene) were used. An initial center wavelength

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at 0.86 µm with a +/- 0.05 µm bandwidth was tested. A tool from Michael Griffin from the Massachusetts Institute for Technology, Lincoln Labs (MIT/LL) was modified and used to create radiance files for the tests. An ASCII reader was a powerful addition to the code, allowing ASCII formatted spectral response function (SRF) to be convolved to the radiance files. Using the ASCII SRF it is possible to create a user-defined SRF or use existing SRFs. The ASCII SRF reader was used to assess different bandwidths for the 0.86 µm channel.

The initial bandwidth (+/- 0.05 µm) proved to be too wide. Both sides of the channel began to encounter undesirable atmospheric water vapor absorption f2eatures. Since atmospheric water vapor may vary drastically on short time and small spatial scales, a sensor designed to detect changes in vegetation trends but which includes atmospheric water vapor absorption features may lead to misinterpretation of atmospheric water vapor influence. When atmospheric water vapor gradients are present, indices such as the Normalized Vegetative Difference Index (NDVI) will appear to reflect changes in vegetation when in actuality the vegetation amounts did not change (Kerekes, 1994). It is clear a narrower bandwidth should be selected. The MIT/LL tool was used to create radiance files centered at 0.86 µm with narrower bandwidths. These narrower radiance files were differenced with the original bandwidth file and other narrower radiance files until a bandwidth was determined to sufficiently avoid atmospheric water vapor features, yet produce sufficient signal strength. The selected bandwidth (0.86 µm +/- 0.02 µm) is shown in figure 2.

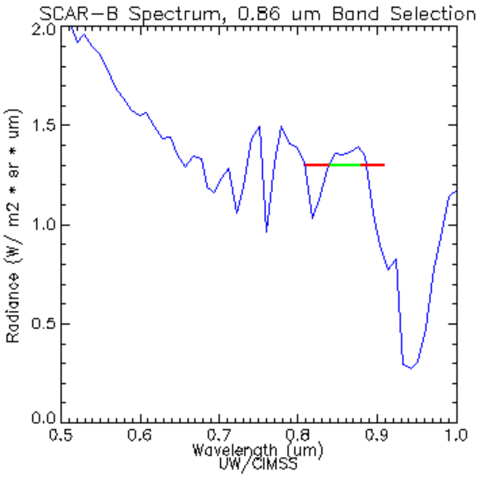

Fig. 2: AVIRIS SCAR-B Wavelength v. Radiance (blue). The red line represents the original 0.86 µm bandwidth. The green line represents the selected bandwidth. Notice the selected bandwidth sufficiently avoids atmospheric water vapor absorption.

3. 1.38 µm CHANNEL

The 1.38 µm channel will be used to detect very thin cirrus clouds during daylight hours. Like the 0.86 µm channel, the 1.38 µm channel is used on other instruments such as the Visible Infrared Imager/Radiometer Suite (VIIRS) and MODIS. An initial ABI center wavelength (1.375 µm) and bandwidth (+/-0.015 µm) was based on MODIS. The SCAR-B and Linden AVIRIS scenes were used to test for surface detection; the cirrus/cumulus cloud scene was used to test for lower troposphere cloud detection. The same approach was used to test proposed wavelength and bandwidth specifications of the 1.38 µm channel as for the 0.86 µm channel.

The 1.38 µm spectrum is characterized by strong atmospheric water vapor absorption. Unlike the 0.86 µm channel, the 1.38 µm channel needs to be positioned *within* the atmospheric water vapor absorption feature to prevent surface and lower troposphere reflected solar radiation from reaching the sensor. This requires choosing a center wavelength and bandpass that roughly maximizes atmospheric water vapor absorption in the channel. Figure 3 shows that at wavelengths shorter than 1.35 µm, the atmosphere rapidly becomes sensitive to reflected solar radiation from the surface and lower troposphere. For wavelengths longer than 1.41 µm, the atmosphere gradually becomes more sensitive to reflected solar radiation from the lower troposphere, but at a drastically smaller rate than towards shorter wavelengths.

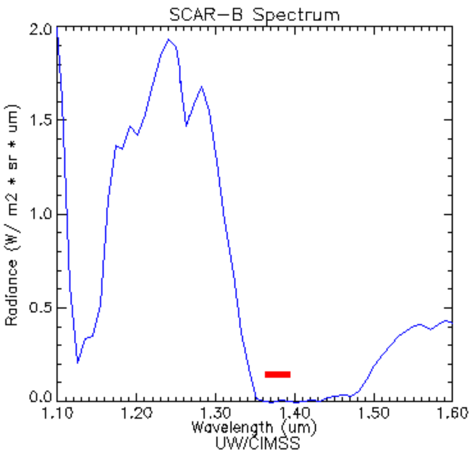

Fig. 3: AVIRIS SCAR-B Wavelength v. Radiance near 1.38 µm (blue). Notice the selected bandwidth (red) in relation to the rapid increase of transmitted radiance towards wavelengths shorter than 1.38 µm.

By producing and differencing radiance files as described with the 0.86 µm channel, it was found that shifting the center wavelength from 1.375 µm to 1.380 μm, away from the steep increase in atmospheric transmittance reduced surface and lower troposphere reflection contribution to the total signal strength.

4. OUT-OF-CHANNEL RADIATION LEAKS

The bandwidth specifications given in the previous sections are for the 50% (or half-max) power points. The SRF can be broken into two different contributing regions. The in-channel region extends from the short wavelength 1% power point through the central wavelength to the long wavelength 1% power point. The out-of-channel region includes all response outside of the in-channel region. Out-of-channel response may be due to filter "leaks" or optical crosstalk that allows light from wavelengths outside the in-channel spectral region to strike the detector. Typically, out-of-channel signal is small. However, for low signal channels such as the proposed ABI 1.38 μm channel, out-of-channel signal must be closely monitored to ensure minimal influence on the total signal. Current ABI specification literature states: "The out of channel response is defined...as one minus the integrated response between the 1% response points divided by the integrated response from 0.3 microns to 20 microns. Out of channel response **shall** be less than 0.1% (0.001) of the total signal when viewing either a 300 K blackbody (for channel wavelengths > 3 microns) or a 100% albedo scene above the atmosphere assuming no attenuation."

It is necessary to determine if the out-of-channel specification is sufficient. For example, an out-of-channel radiance contribution that is too large in the 1.38 μm channel could allow surface reflection detection. This would defeat the purpose of the 1.38 μm channel to detect only thin cirrus clouds and not surface features. MODIS has channels very similar to the 1.38 μm and 0.86 μm ABI channels, so MODIS data were chosen to test the ABI specifications. Radiance files were created from the AVIRIS data scenes using MODIS SRF in ASCII format. For each scene and channel, a radiance file was created using the in-channel spectral region and another using the in-channel plus the out-of-channel spectral region. The goal is to create a ratio of out-of-channel radiance to in-channel radiance. The ratio of out-of-channel to in-channel radiation is defined in equation 1.

$$\frac{((\text{Out-of-Channel} + \text{In-Channel}) - \text{In-Channel})}{\text{In-Channel}}$$

Eq. 1: Equation used to define out-of-channel to in-channel ratio.

Convolving MODIS spectral characterization with AVIRIS data shows that the MODIS 0.86 μm and 1.38 μm channels perform well for vegetation and thin cirrus discrimination, respectively. Thus, if the ratio of the out-of-channel to the in-channel radiances for the MODIS data is greater than the ABI specification (i.e. 0.1% or 0.001) it would indicate the ABI specification is sufficient as written. Table 1 shows the results for the MODIS out-of-channel to in-channel radiance ratio for each of the AVIRIS data scenes.

Scene	Min 0.86 μm Out/In Ratio Value	Min 1.38 μm Out/In Ratio Value
SCAR-B	0.0012*	0.0369
Cirrus	N/A	0.0019
Linden	0.0002*	0.0039

Table 1: Shows the ratio of out-of-channel radiation to in-channel radiation. *Note for the 0.86 μm channel in the SCAR-B scene there were a few ratios below 0.0012, but those were at a river, which would not impact vegetation indices. Also for the Linden 0.86 μm channel the smallest ratios (0.0002) were in a large smoke plume; ratios where the surface was detectable were all greater than 0.001.

Table 1 shows the 0.86 μm MODIS out-of-channel to in-channel ratios are all greater than the ABI specification (0.001), showing the ABI specification for the 0.86 μm is sufficient and should result in high quality 0.86 μm data. The 1.38 μm MODIS out-of-channel to in-channel ratios are also all greater than the ABI specification (0.001) and again the ABI specifications are sufficient and should result in high quality 1.38 μm data.

5. TRANSMITTANCE VERSUS TOTAL PRECIPITABLE WATER

As stated above, the 1.38 μm ABI channel is spectrally positioned in an atmospheric water vapor absorption region. It is important to define a unit measurement for the total amount of water vapor in the atmosphere. The total amount of water vapor in the atmosphere can be defined as the total amount of water (typically in millimeters) that would be measured if all the water vapor in a column of air fell as precipitation, known as total precipitable water (TPW). TPW values vary greatly from the tropics, where it possible to have near 70 mm of TPW, to the polar regions where TPW values can be as low as one millimeter. TPW values also vary greatly from season to season in the mid-latitudes. It is then critical to determine how different amounts of TPW will affect solar transmittance and hence surface detection in the 1.38 μm ABI channel.

To examine the effects of different TPW values an atmospheric modeling program known as MODTRAN was used (Anderson et al, 1999). MODTRAN inputs were a tropical temperature and moisture profile, with a solar zenith angle set at nadir. A tropical scene was chosen because of its large water vapor carrying capacity. In the examination, the TPW amount was varied through a scaling factor to emulate dry to very moist conditions. This provided insight on the influence of TPW on atmospheric transmittance. Additionally, solar radiation travels the shortest path to the surface and back to space when the solar zenith angle is set to zero (i.e. nadir). For mid-latitude or polar regions, the solar zenith angle should be set to non-zero since solar radiation travels a much longer path to the surface and back to a satellite imager in those latitudes. The MODTRAN software outputs transmittance values for desired pressure levels from the top of the atmosphere to the surface. TPW values ranged from 65.8 mm to 0.4 mm for the modified tropical profile. Results showed TPW values greater than 12 mm would adequately absorb surface reflected solar radiation; for TPW values less than 6 mm the 1.38 µm channel effectively becomes a window channel. Figure 4 is a plot of transmittance squared (two-way transmittance) versus pressure for many TPW values.

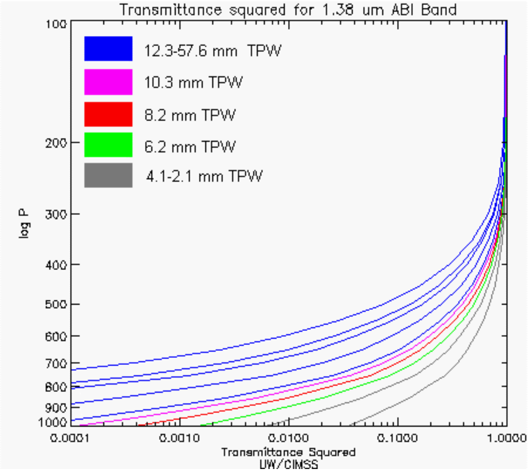

Fig. 4: Transmittance squared v. pressure. Note transmittance squared was chosen over just transmittance to reflect the two-way path solar radiation must take to be detected by a satellite.

It is clear from Fig. 3, that a transition takes place between 12.3 mm of TPW and 4.1 mm of TPW. With TPW values equal to or greater than 12.3 mm, the atmosphere absorbs nearly all of the surface reflected radiation near 1.38 µm; when TPW is equal to or less than 4.1 mm, the atmosphere allows radiation to pass through and potentially be detected by a satellite imager. It can be concluded that the 1.38µm ABI channel will not detect the surface as long as TPW values remain above 12 mm, but as TPW values fall below 12 mm, surface reflection will add ambiguity to thin cirrus retrievals.

6. CONCLUSION

The ABI will provide unprecedented spatial and temporal resolution on the GOES satellites. The 0.86 µm channel will be widely used to monitor vegetation trends which will help forecast fire danger and assess the effects of climate change. The power of a GOES perspective as opposed to a polar orbiting pass is that GOES offers nearly continuous monitoring, enhancing cloud clearing so that the vegetation influence on the 0.86 µm channel may be isolated. The 1.38 µm channel will provide effective thin cirrus detection when TPW exceeds 12 mm, aiding forecasts, numerical weather prediction and nowcasting. In addition, thin cirrus detection is important for generating an array of surface products. For more information:
http://cimss.ssec.wisc.edu/goes/abi/vis_IR.html

7.ACKNOWLEDGMENTS

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