Spectral Characteristics of the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS)

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ABSTRACT

The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument scheduled for flight on the AM (1030 hours equator crossing time) and the PM (1330 equator crossing time) platforms of the Earth Observing System (EOS). It has a considerable multispectral capability for observations of land, ocean and atmospheric features. The 36 bands sampling the visible, near infrared and thermal infrared portions of the spectrum along with 250 to 1000 meter resolution will offer very powerful observing advantages over heritage instruments such as the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA environmental satellites. The engineering model of the MODIS is under construction and so far the performance being observed is generally meeting specifications. Preliminary analyses of components of the engineering model indicate that it will meet most of the spectral specifications with some variances relative to the specifications being required and approved. Overall MODIS fabrication is on schedule for its first flight in 1998.

1. INTRODUCTION

The first flight of the MODIS will be on the EOS AM platform (equator crossing southbound at approximately 1030 local time) in mid-1998. The MODIS will also be on the PM platform (equator crossing northbound at approximately 1330 local time) scheduled for launch in late 2000. Both spacecraft will be orbiting at a 705 km altitude with a 16-day repeat period. Through the launch of multiple spacecraft with design lifetimes of up to 6 years, data-sets spanning as many as 18 years are to be acquired.

2. OVERVIEW OF MODIS CHARACTERISTICS

Table 1 lists the general characteristics of MODIS. MODIS uses the latest in technology to get optimum performance. It is a relative large instrument due to the scanning capability (+/- 55 degrees cross-track) required to provide nearly daily coverage and the number of bands and focal planes necessary. The fabrication of MODIS is proceeding very well. Figure 1 shows the engineering model under fabrication at the Santa Barbara Research Center in Goleta, California.

MODIS has 36 bands spanning the electromagnetic spectrum from 400 nanometers to 14 micrometers (Table 2). Nineteen (19) of the bands will observe reflected solar radiation and seventeen (17) of the bands principally observe emitted thermal radiation. Two of the MODIS bands have a spatial resolution at nadir of 250 meters, five bands have a 500 meter resolution, and the remaining bands have a 1000 meter resolution. The placement of the band center wavelengths for bands 1-7 are derived from the heritage of the Landsat Thematic Mapper (TM). Bands 8-16 are bands for observing ocean color and for improved observations relative to the Nimbus Coastal Zone Color Scanner. Even though these two groups of bands overlap spectrally in many instances, the two groups of bands have very different dynamic ranges. Bands 1-7 must observe land features creating reflected solar radiation from vegetation, snow and clouds while bands 8-16 observe ocean color where the combined ocean-atmosphere radiances are relatively small. Bands 20 and 22-36 were selected to observe features in the troposphere and are derived from the heritage of the NOAA High Resolution Infrared Sounder (HIRS) unit. Band 26 was recently changed from being a four micron band to one at 1.38 micrometers. It is expected that this band will very effectively observe the extent of cirrus clouds. Bands 17-19 are special bands for improved observations of atmospheric water vapor at relatively low altitudes compared to the capability normally possible with thermal infrared bands (e.g., bands 27-32) as well as some cloud properties. Band 22 is a thermal band with a large dynamic range (up to 400 degrees Kelvin) placed there for observing the onset of volcanic eruptions and attendant lava flows plus the extent of fires associated with "slash and burn" deforestation. Bands 31 and 32 also have a dynamic range extending to 400K.

Figure 2 provides a sketch of how MODIS is intended to function, in a broad sense, when the instrument fabrication is completed by the Hughes/Santa Barbara Research Corporation (SBRC) under contract to NASA's Goddard Space Flight Center. The layout of the spectral bands in four different focal planes, two of which are radiatively cooled, is sketched in Figure 2. These bands will be registered to within 0.2 pixel with a goal of 0.1 pixel wherever possible. MODIS fabrication and operation will place a great deal of emphasis on having an on-orbit capability to monitor the calibration of the instrument and other aspects of its operation as it affects the integrity and quality of the received data. Calibration will use the moon (through a space view and, possibly, through maneuvering the spacecraft) and the sun (using a diffuser plate) for calibration of reflected solar radiation bands (5% absolute and 2% relative to the sun) and a blackbody (grooved plate) for checking the calibration of the thermal bands (1% absolute). Besides offering another means for radiometric calibration, another device in the instrument called the Spectral Radiometric Calibration Assembly (SRCA) will allow spectral calibration and the registration of the bands to each other and between focal planes to be monitored. Any shifts spectrally of the bandpass filters will also be observed to an accuracy of 1 nanometer and a precision of 0.5 nanometer. Registration between bands will be observed to an accuracy of 0.1 pixel.

The MODIS design is highly modular[1]. The main instrument modules are: (1) the mainframe assembly including covers and doors; (2) the scan mirror assembly; (3) the afocal telescope assembly; (4) the aft optics assembly including the dichroic subassemblies, four objective subassemblies and the visible and near infrared focal plain assembles (FPA's); (5) the radiative cooler assembly with the short-wave/mid-wave and longwave infrared FPA's; (6) the space-viewing analog electronics module; (7) the forward-viewing analog electronic module; (8) the main electronic module; (9) the calibration modules including the solar diffuser assembly, the solar diffuser stability monitor, the SRCA, and the blackbody assembly. The MODIS mainframe is a beryllium bonded and bolted rigid assembly consisting of three primary bulkheads and support panels to which other modules, covers and mounting feet are attached. The scan mirror is a double-sided, continuously rotating single piece of beryllium that is electro-discharge machined for light-weighting, nickel-plated, and silver-coated. It is 58 by 21 centimeters in size and roughly elliptical in shape weighing approximately 4.3 kilograms. The telescope assembly consisting of the various mirrors uses an off-axis, afocal Gregorian telescope (17.8 centimeter, unobscured, aperture). All this is mounted on a graphite epoxy optical bench.

3. MODIS MULTISPECTRAL OBSERVATIONS OF LAND, OCEAN AND ATMOSPHERIC FEATURES

The power and uniqueness of MODIS lie principally in the fact that congruent and simultaneous observations can be obtained for both atmospheric features as well as land and ocean features that are often interdependent and complementary both for remote sensing and geophysical parameter estimation purposes. Uncertainties that often exist when multispectral observations are taken from different instruments looking through different parts of the atmosphere at different angles and different times are removed through the MODIS capability.

For land surface studies the reflected solar radiation bands will be useful for observing the extent of various land cover types and the condition of these land covers[2]. It is expected that it should be possible to provide improved observations of the extent of vegetation types, snow cover, etc., through the better spatial resolution (250 and 500 meters) relative to the present NOAA Advanced Very High Resolution Radiometer (AVHRR) and, for example, to observe the distribution of photosynthetic activity or condition for vegetation classes using bands 1-7 as well as the surface temperature bands (e.g., 20, 28, 31 and 32). The power of MODIS is manifested in this case as well as others when one applies the built-in capability to correct for the effects of the atmosphere using those bands that, for example, help to correct for the presence of water vapor in the atmosphere (17-19, 27-29, 31 and 32), ozone (30) and aerosols (best over darker backgrounds using various bands, see Table 1). As previously noted MODIS also offers a new capability for observing hot features using specially placed bands with much larger dynamic range than heretofore available.

Over the oceans both ocean color and sea surface temperature will be observed concurrently enabling flow visualization and upwelling areas to be better observed as well as estimates of ocean-atmosphere interaction. As in the case of observing surface land feature, The combination of thermal and reflected solar radiation bands also allows several approaches to be employed or used together to calculate and removed the effects of the atmosphere for ocean surface observations. This is a particularly important point for observing ocean color in that a very large fraction of the radiance observed at satellite altitude over the clear ocean comes fro the atmosphere.

While the ability to allow corrections for the effect of the atmosphere using inherent MODIS capabilities has been emphasized in the previous paragraphs, MODIS offers some very useful capabilities for observing properties of the Earth's atmosphere, principally in the troposphere[3]. The MODIS will spectrally provide, in the thermal infrared region, the capability for observing tropospheric properties similar to the NOAA HIRS, but, additionally, will provide this spectral capability along with a 1

kilometer spatial resolution capability. In this part of MODIS the rough vertical distribution of temperature and water vapor will be observed along with the providing total column ozone amounts day and night using band 30 at 9.73 micrometers. The spectral capability in bands 1-7 will help to observe the extent of clouds at 250 - 500 meters as well as provide estimates of effective droplet size, cloud phase (ice or water) and optical depth. As noted previously, band 26 has recently been added to MODIS for observing the extent of cirrus based upon work done with the AVIRIS aircraft instrument[4]. As already noted bands 17-19 will further add detail concerning atmospheric water vapor and relatively low altitudes.

4. MODIS SPECTRAL SPECIFICATIONS AND EXPECTED RESULTS

MODIS has very specific and relatively tight specifications for the spectral bands[4]. Table 3 lists the locations of the bands shown in Table 2 along with the tolerance allowed on the location of the center wavelength and the bandwidth. Figure 3 offers the terms used in describing the characteristics of the spectral bands. With these terms in mind, as well as others, some relevant specifications and descriptions follow[5].

a. Band edge: the wavelength at which the response is half of the peak response. This, of course, refers to a lower and upper band edge.

b. Center wavelength: the wavelength midway between the band edges.

c. Bandpass (or bandwidth): the wavelength interval between the lower and upper band edges. This is also referred to as the Full Width Half Maximum (FWHM) response.

d. One-percent response point: The wavelength, nearest to the center wavelength, at which the reponse is one-percent of the peak response; there is a lower and an upper one-percent response point. Each one-percent response point shall be within 1.5 times the bandpass from the corresponding band edge.

e. Extended bandpass: the wavelength interval between the lower and upper one-percent response points.

f. Out-of-band response regions: the spectral regions beyond the extended bandpass.

g. Out-of-band response: the ratio of the integrated out-of-band spectral response to the integrated extended bandpass spectral response. This ratio includes both the upper and lower wings of the response. This shall be less than 5%.

h. Out-of-band blocking: the inverse of the ratio defined as the out-of-band response.

i. Edge range: the wavelength interval, in nanometers, between 5% of the peak response and 80% of the peak response. The edge range shall not exceed 50% of the bandwidth in any spectral band.

j. Ripple: this is the response between the 80% of peak points of the bandpass. This ripple shall always exceed 80% of the peak response; i.e. no response shall go below 80% of the peak response between the 80% peak response points in the spectral band response.

Table 3 also shows the expected center wavelengths and bandwidths based on measured or modeled results. Figures 4-7 show the expected system spectral response for all the spectral bands on the four focal planes of MODIS. These system spectral response curves are preliminary. A number of the components contributing to the system spectral response are modeled rather than measurements. In addition the results presented herein have not been analyzed fully by the MODIS contractor-Santa Barbara Research Corporation (SBRC). The figures reflect piece part data for the detectors, visible and near infrared dichroics and coatings, and 20 of the 36 filters (bands 1-4, 8-19, and 27-30 -- see Table 2). Modeled data are used for the optics, remaining coatings, emissive band dichroics, and the remaining filters. The data used are for unnormalized transmittance (unitless) as a function of wavelength. The profiles cover the range of piece-part measured data, which means that the cut-off at the edges of the bandwidth was determined by the measurements. Out-of-band responses are incomplete for all bands.

5. SUMMARY AND CONCLUSIONS

MODIS will provide some very interesting and powerful capabilities for multispectral observations of conditions in the troposphere and the extent and condition of parameters on the land surface and in the surface waters of the ocean and large water bodies. The MODIS fabrication is at the engineering model stage. On the basis of results seen so far from the engineering model and its components, MODIS appears to be coming together nicely and the spectral response is meeting specifications with minor exceptions. Many of the spectral response results shown here are based upon modeling. These results should be corroborated in the near future as system level measurements become available from the engineering model and then the protoflight model. Excitement among the MODIS Science Team members is building as the MODIS is coming together. There is great promise for MODIS realizing its potential for providing very exciting measurements of Earth-atmosphere system parameters through the use of state-of-the-art technologies and fabrication techniques.

6. ACKNOWLEDGMENTS

Appreciation is expressed to all members of the MODIS Technical and Science Teams, plus the EOS Projects personnel who are so ably and expertly bringing the MODIS instrument to fruition.

7. REFERENCES

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4. B.-C. Gao and Y. J. Kaufman, "Selection of the 1.375 μm MODIS Channel for Remote Sensing of Cirrus Clouds and Stratospheric Aerosols from Space", accepted for publication in *Journal of the Atmospheric Sciences*, 1995.

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Table 1: A general summary of MODIS characteristics (as of March 1995).

PARAMETERS	DESIGN SPECIFICATIONS OR EXPECTED PERFORMANCE
PLATFORM ALTITUDE	705 km (10:30AM, 1:30 PM)
IFOV (no. of bands@ IFOV)	36: 29@1000m 5@500m 2@250m
SWATH	110 DEG/2330 KM
SPECTRAL BANDS	(20/0.4-3.0 µm; 16/3-15 µm
SPECTRAL RESOLUTION	10 nm to 500 nm
RADIOMETRIC ACCURACY	5% ABSOLUTE, <3 mm 1% ABSOLUTE, >3 mm (possibly <0.3%) 2% REFLECTANCE
QUANTIZATION	12 BIT
POLARIZATION SENSITIVITY	2 % MAX, <2.2 mm
MODULATION TRANSFER FUNCTION	0.3 AT NYQUIST
S/N PERFORMANCE (70 DEGREE SOLAR ZENITH/OCEANS)	830:1 (443 nm) 745:1 (520 nm) 503:1 (865 nm)
NEDT PERFORMANCE (THERMAL BANDS) @ 300 DEG K/WINDOW BANDS	LESS THAN 0.05
SCAN EFFICIENCY	30 %
INTEGRATION TIME	83 - 333 µ-sec
SIZE (APPROX)	1.1 X 1.6 X 1.2 M
WEIGHT	<250 kg (222 kg)
POWER	<200 w (137 w)
PEAK DATA RATE	~11 MBS (daytime)
DUTY CYCLE	100 %

Table 2: A summary of MODIS bands and their purposes.

BAND	CENTER *	IFOV (m)	WIDTH	PURPOSE
	LAND AND CLOUD BOUNDARIES BANDS			
1	645	250	50	VEG CHLOROPHYLL ABS LAND COVER TRANSFORMATION
2	858	250	35	CLOUD AND VEGETATION LAND COVERTRANSFORMATION
	LAND AND CLOUD PROPERTIES BANDS			
3	469	500	20	SOIL, VEGETATION DIFFERNCES
4	555	500	20	GREEN VEGETATION
5	1240	500	20	LEAF/CANOPY PROPERTIES
6	1640	500	20	SNOW/CLOUD DIFFRNCES
7	2130	500	50	LAND & CLOUD PROPERTIES
	OCEAN COLOR BANDS			
8	412	1000	15	CHLOROPHYLL OBSERVATIONS
9	443	1000	10	CHLOROPHYLL OBSERVATIONS
10	488	1000	10	CHLOROPHYLL OBSERVATIONS
11	531	1000	10	CHLOROPHYLL OBSERVATIONS
12	551	1000	10	SEDIMENTS
13	667	1000	10	SEDIMENTS, ATMOSPHERE
14	678	1000	10	CHLOR. FLUORESCENCE
15	748	1000	10	AEROSOL PROPERTIES
16	869	1000	15	AEROSOL/ATM PROPERTIES
	ATMOSPHERE/CLOUD BANDS			
17	905	1000	30	CLOUD/ATMOSPHERE PROPERTIES
18	936	1000	10	CLOUD/ATMOSPHERE PROPERTIES
19	940	1000	50	CLOUD/ATMOSPHERES PROPERTIES
26	1.375	1000	30	CIRRUS CLOUDS
	THERMAL BANDS			
20	3.75	1000	0.18	SEA SURFACE TEMPERATURES
21	3.96	1000	0.0563	FORESTFIRES/VOLCANOES
22	3.96	1000	0.0594	CLOUD/SURFACE TEMPERATURE
23	4.05	1000	0.0608	CLOUD/SFCTEMPERATURE
24	4.47	1000	0.065	TROPOSPHERETEMP/CLOUD FRACTION
25	4.52	1000	0.067	TROP TEMP/CLFRACTION
27	6.72	1000	0.36	MID-TROPOSPHERE HUMIDITY
28	7.33	1000	0.30	UPPER-TROPOSPHERE HUMIDITY
29	8.55	1000	0.30	SURFACE TEMPERATURE
30	9.73	1000	0.30	TOTAL OZONE
31	11.03	1000	0.50	CLOUD/SURFACETEMPERATURE
32	12.02	1000	0.50	CLOUD/SURFACE TEMPERATURE
33	13.34	1000	0.30	CLOUD HEIGHT & FRACTION
34	13.64	1000	0.30	CLOUD HEIGHT & FRACTION
35	13.94	1000	0.30	CLOUD HEIGHT & FRACTION
36	14.24	1000	0.30	CLOUD HEIGHT & FRACTION

* BAND CENTER AND BANDWIDTH ARE IN NANOMETERS FOR BANDS 1-19, 26 AND MICROMETERS FOR BANDS 20-25, 27-36

Table 3: Preliminary Measured/Modeled MODIS Center Wavelengths and Bandwidths (as of 2/3/95)

Band Number	Specification CenterWavelength (CW) (nm)	Specification CW Tolerance (nm)	Calculated BW (nm)	Specification Bandwidth (BW) (nm))	Specification BW Tolerance (nm)	Calculated BW (nm)
1	645	4	644.4	50	4	49.7
2	858	2.2	855.9	35	4.3	37.2
3	469	4	465.6	20	2.8	19.2
4	555	4	553.3	20	3.3	19.7
5	1240	5	1240.1	20	7.4	20.0
6	1640	7	1640.1	24.6	9.8	24.6
7	2130	8	2130.0	50	12.8	50.1
8	412	2	411.3	15	1.5	14.8
9	443	1.1	442.2	10	1.6	11.0
10	488	1.2	486.9	10	1.7	10.8
11	531	2	529.8	10	1.9	12.0**
12	551	5	547.1	10	1.4	10.6
13	667	+1,-2	665.2	10	1.7	10.1
14	678	1	676.7**	10	1.7	11.4
15	748	2	746.3	10	1,9	10.0
16	869	5	865.6	15	4.3	15.9
17	905	2.3	904.1	30	5.4	34.4
18	936	2.3	935.4	10	5.6	13.6
19	940	2.4	935**	50	5.6	48.2
20	3750	19	3749.7	180	22.5	181.6
21	3959	20	3959.2	59.4	23.8	59.8
22	3959	20	3959.2	59.4	23.8	59.8
23	4050	20	4050.1	60.8	24.3	61.2
24	4465	22	4464.2	65	26.8	63.8
25	4515	22	4513.0	67	27.1	65.8
26	1375	6	1375.1	30	8	30.0
27	6715	34	6717.1	360	40.3	363.4
28	7325	37	7348.8	300	44	321.4
29	8550	43	8549.2	300	51.4	311.6
30	9730	49	9760.7	300	58.4	314.4
31	11030	55	11017.2	500	66.2	498.6
32	12020	60	12045.1	500	72.1	518.0
33	13335	67	13361.7	300	80	310.2
34	13635	68	13675.9	300	81.8	329.6
35	13935	70	13913.9	300	83.6	318.0
36	14235	71	14194.1	300	85.4	318.3

**deviation approved by Goddard Space Flight Center MODIS Project

Figure 1: The MODIS engineering model in fabrication at the Santa Barbara Research Corporation (SBRC) facilities in Goleta, California

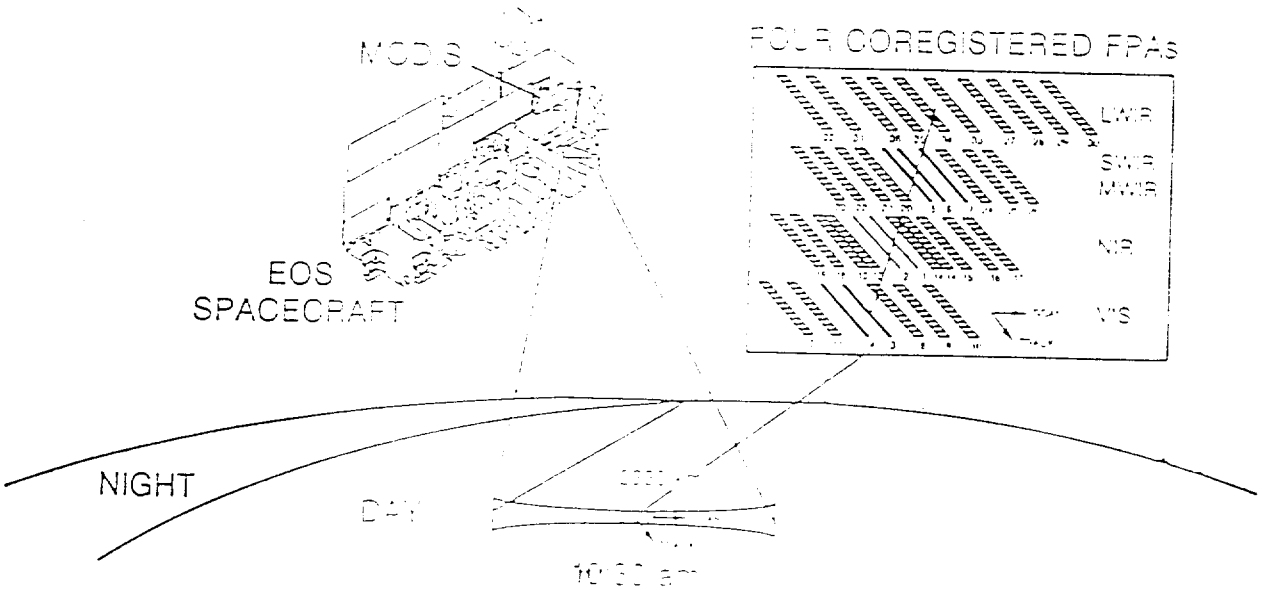

Figure 2: A sketch showing the [illegible] MODIS instrument and its operation in orbit

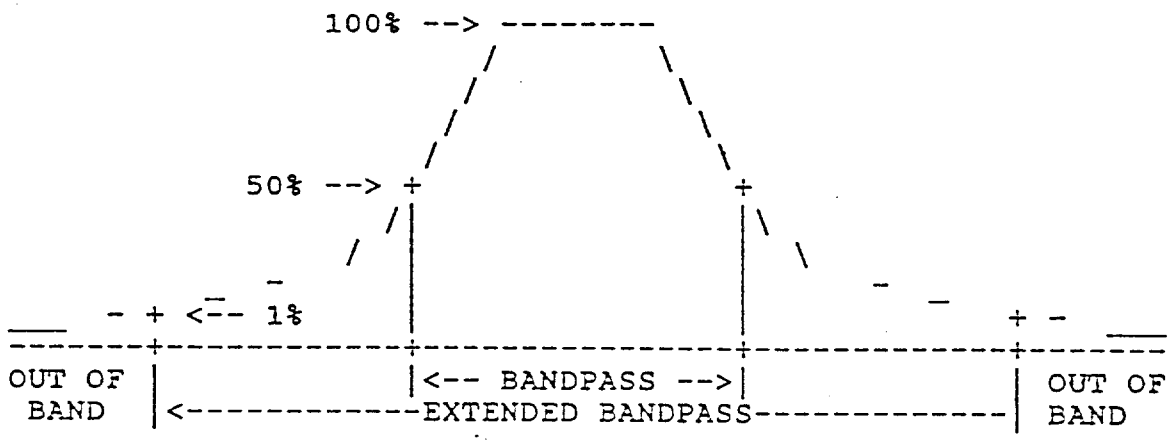

FIGURE 3.3.3.1

Figure 3: A sketch showing the various terms used in spectral bandpass specifications for the MODIS

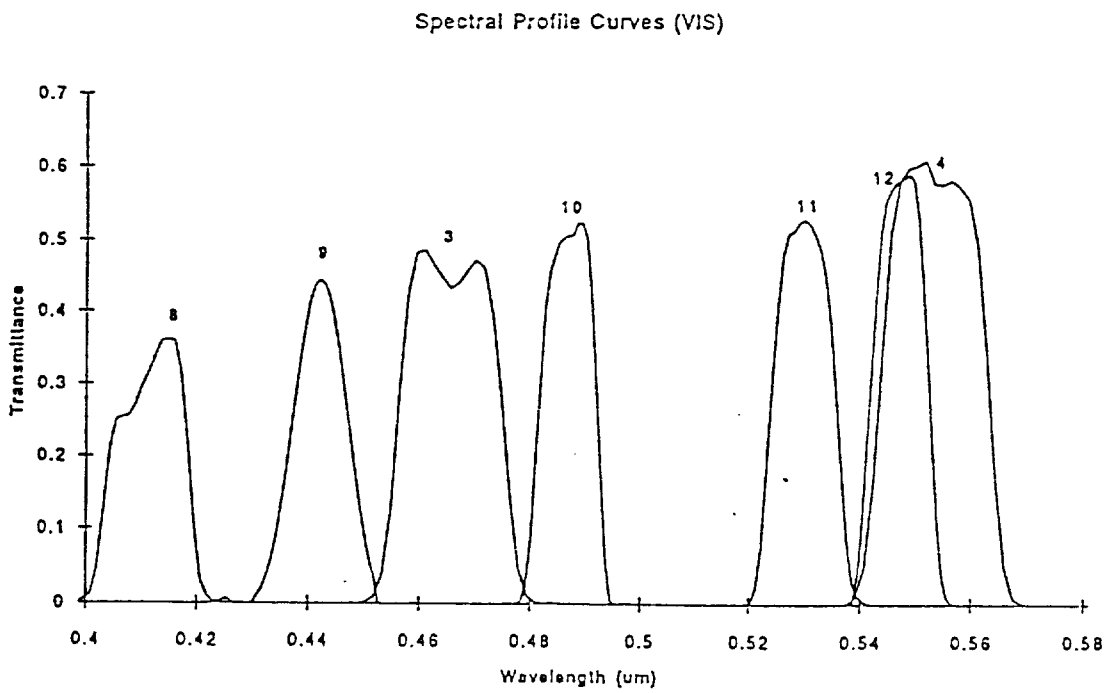

Figure 4: Spectral profile curves for MODIS bands 3, 4, 8-12 on the "visible/VIS" focal plane.

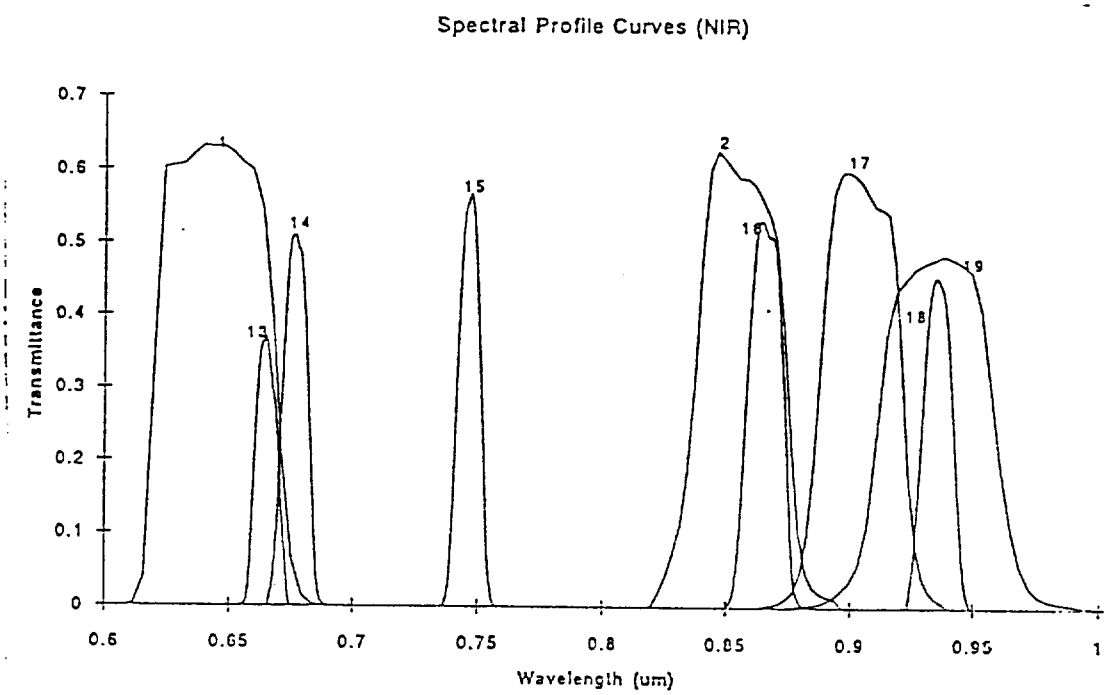

Figure 5: Spectral profile curves for MODIS bands 1, 2, 13-19 on the "near infrared/NIR" focal plane.

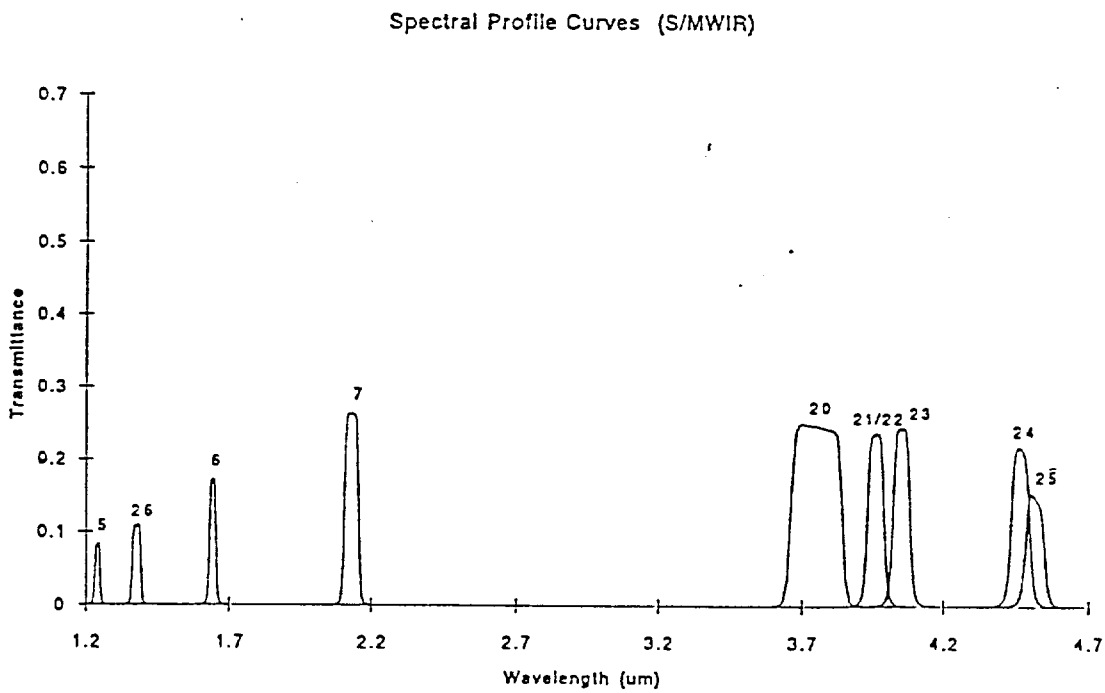

Figure 6: Spectral profile curves for the MODIS bands 5-7, 20-26 on the cooled, "short-wave infrared/mid-wave infrared/S/MWIR" focal plane.

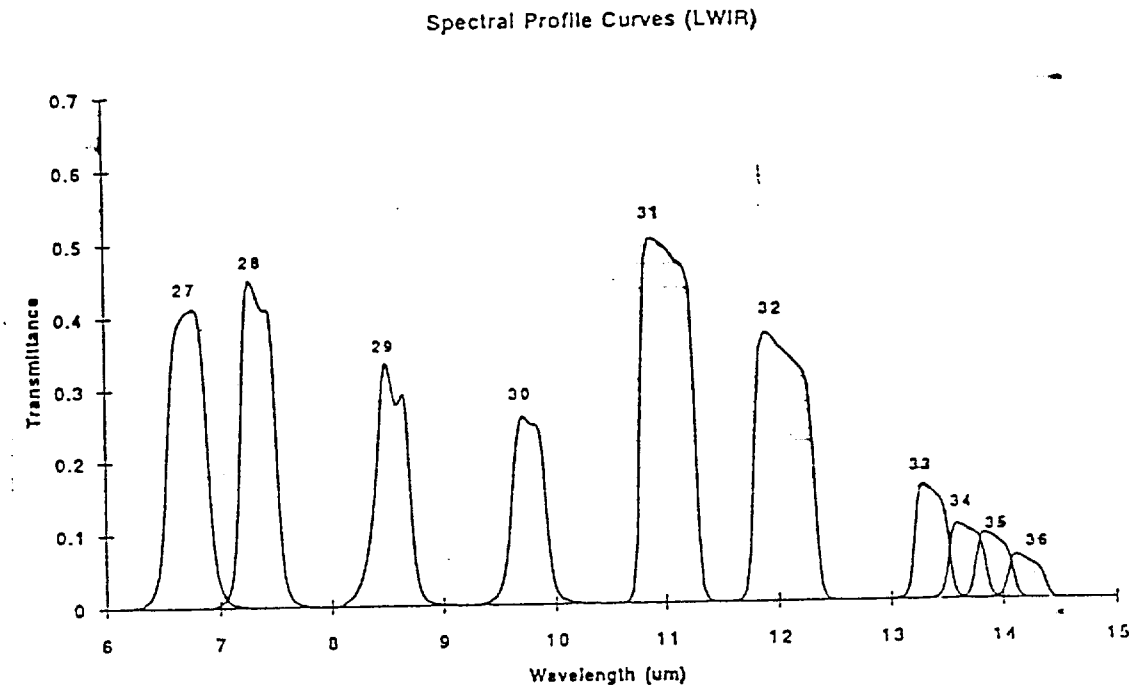

Figure 7: Spectral profile curves for the MODIS bands 27-36 on the cooled, "long-wave infrared/LWIR" focal plane.