Requirements for a Moderate-resolution Infrared Imaging Sounder (MIRIS)

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ABSTRACT

The high cost of imaging and sounding from space warrants exploration of new methods for obtaining the required information, including changing the spectral band sets, employing new technologies and merging instruments. In some cases we must consider relaxation of the current capability. In others, we expect higher performance. In general our goal is to meet the VIIRS and CrIS requirements while providing the enhanced next generation capabilities: 1) Hyperspectral Imaging in the Vis/NIR bands, 2) High Spatial Resolution Sounding in the Infrared bands. The former will improve the accuracy of ocean color products, aerosols and water vapor, surface vegetation and geology. The latter will enable the high-impact achieved by the current suite of hyperspectral infrared sounders to be achieved by the next generation high resolution forecast models. We examine the spectral, spatial and radiometric requirements for a next generation system and technologies that can be applied from the available inventory within government and industry. A two-band grating spectrometer instrument called the Moderate-resolution Infrared Imaging Sounder (MIRIS) is conceived that, when used with the planned NASA PACE Ocean Color Instrument (OCI) will meet the vast majority of CrIS and VIIRS requirements in the all bands and provide the next generation capabilities desired. MIRIS resource requirements are modest and the Technology Readiness Level is high leading to the expectation that the cost and risk of MIRIS will be reasonable.

Keywords: Infrared, Sounding, Imaging, NASA, MIRIS

1. INTRODUCTION

Imaging and sounding of Earth's atmosphere have been essential observations for NASA, NOAA, and DoD science and operations since the mid 1960's[1]. The most recent US imagers and sounders currently in operations include the Moderate Resolution Imaging Spectroradiometer (MODIS)[2] and the Atmospheric Infrared Sounder (AIRS)[3] on the Aqua spacecraft and the Visible Infrared Imager Radiometer Suite (VIIRS) and Cross-track Infrared Sounder (CrIS) on the Suomi NPP spacecraft. NASA's MODIS instrument is a filter radiometer and provides global daily imagery with 36 spectral bands ranging from 0.4-14.4 μm at spatial resolutions ranging from 0.25 to 1.0 km at nadir. MODIS footprints grow with scan angle, but the wide 2330km swath provides global daily coverage at the equator. NASA's AIRS instrument is a hyperspectral infrared grating spectrometer instrument that covers the infrared spectrum from 3.7-15.4 μm with 2378 channels. AIRS also has a wide swath, but with a coarser, 13.5 km spatial resolution at nadir. MODIS and AIRS uses linear detector arrays for the focal plane. CrIS is a Fourier Transform Spectrometer (FTS) covering the same bands as AIRS with similar spectral and spatial resolution. CrIS has three bands (objectives and focal plane assemblies), each consisting of a 3x3 array of detectors each sharing a common interferometer in the object space of the optical system: shortwave (SW), midwave (MW) and longwave (LW). The VIIRS has fewer channels than MODIS, (22 in VIIRS, vs 36 in MODIS). The most notable difference is in the imaging performance; the VIIRS has nearly constant resolution across the scan line. Water vapor channels (5-8 μm), and temperature sounding channels (12.5-15.5 μm) are eliminated and it includes a low-light-level Day/Night imaging band. These instruments have proven their value for operational weather forecasting and Earth science research through their use in thousands of peer reviewed publications and their high impact on operational weather forecasting[4,5].

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Next generation capabilities for imaging and sounding call for higher spatial and spectral resolution from these instruments[6,7,8] and improved calibration accuracy to be consistent with the next generation of advanced data product algorithms and higher spatial resolution weather forecast models. The planned NASA Ocean Color Instrument (OCI) on the Pre-Aerosol oceans Clouds and Ecosystems (PACE) can provide the advanced capabilities needed for the solar reflective bands[1]. In this paper we focus on the requirements for an infrared imager/sounder to complement the OCI and meet all requirements for imaging and sounding in the two instruments. Infrared imager/sounder concepts have been developed in the past, (e.g. ARIES)[9,10,11,12], and the Advanced Low Earth Sounder (ALS)[13] to meet the enhanced requirements by employing advanced technologies developed over the last decade. These technologies include wide field infrared refractive grating spectrometers as developed on the Spaceborne Infrared Atmospheric Sounder (SIRAS) Instrument Incubator Program (IIP)[14,15], and commercial large format focal plane assemblies. The wide field nature of the new optics and focal plane assemblies enable an extended field of view along-track, allowing more time for the instrument to scan the scene and thereby improving the signal collection ability. This extra signal is traded for higher spectral and spatial resolution in these next generation systems.

2. REQUIREMENTS

Here we examine a set of candidate requirements for an infrared system to meet the requirements of the legacy imagers and sounders for atmospheric sounding and infrared imaging. These requirements are notional and do not represent a community consensus or NASA position. They are presented as a concept to solicit community input on the feasibility of such a system to enable improved performance and reduced cost of these systems in the future. In this section we focus on the spectral requirements since they define the data products that can be produced. We only discuss temperature and water vapor sounding for the sounder; additional trace gas species retrievals are possible if the information content is present in the MIRIS bands. Spatial resolution and coverage requirements must be as good or better than the VIIRS for all imaging and sounding bands and will be discussed in the next section. Radiometric requirements (NEdT) must also be comparable to the AIRS and meet the VIIRS requirements.

2.1 Infrared Sounding

Table 1 shows the spectral "bands" for the AIRS instrument compared to the CrIS and the current concept, MIRIS. AIRS has 17 modules including 2378 channels covering the range of 3.7-15.4μm; this design was required to enable a single grating to cover the full spectral range. Multiple orders are used (3 through 11) and linear arrays capture the energy from the grating in a pupil imaging system, i.e. the detectors image the pupil, in this case the scan mirror. AIRS works exceptionally well, but the pupil imaging causes a complex dependence of spatial response and polarization and only allows one field of view to be imaged onto the ground. This greatly limits the energy collection efficiency of the system.

CrIS has three bands as indicated in Table 1 and the bands are more continuous as it uses an FTS. Spectral resolution is a little lower than AIRS but achieves 1302 spectral channels in similar bands. CrIS images a 3 x 3 Pixel Field of View (FOV) of 13.5 km pixels.

The ARIES concept moved to the new wide field grating spectrometer technology developed by SIRAS, but required 4 spectrometers, and 3097 channels, to meet the full range of bands required for the AIRS. There was a concern at the time that it would not be possible to cover an extended range spectrally while achieving the good performance.

Table 1. Spectral Performance of the AIRS compared to CrIS, and the next gen system concept, MIRIS.

AIRS Band	**λ_1 (μm)**	**λ_2 (μm)**	**Nch (-)**	**v_av (cm-1)**	**dv_av (cm-1)**	**dv_samp (cm-1)**
1	3.74	3.92	118	2613.3	2.05	1.06
2	4.11	4.33	130	2369.9	1.85	0.96
3	3.91	4.11	116	2492.2	2.06	1.06
4	4.33	4.61	150	2238.2	1.84	0.95
5	6.94	7.48	192	1387.7	1.03	0.55
6	6.20	6.49	104	1575.6	1.34	0.71
7	6.55	6.85	106	1492.5	1.20	0.63
8	7.47	7.79	94	1310.0	1.11	0.59
9	7.86	8.22	106	1243.7	0.99	0.53
10	8.81	9.48	159	1093.7	0.97	0.51
11	9.57	10.28	167	1008.1	0.82	0.43
12	10.28	10.99	167	940.7	0.70	0.38
13	11.07	11.75	161	876.4	0.60	0.33
14	11.74	12.69	167	818.7	0.70	0.38
15	12.80	13.75	167	753.4	0.59	0.32
16	13.74	14.55	144	706.9	0.50	0.28
17	14.67	15.40	130	665.2	0.44	0.25
CrIS Band	**λ_1 (μm)**	**λ_2 (μm)**	**Nch (-)**	**v_av (cm-1)**	**dv_av (cm-1)**	**dv_samp (cm-1)**
1	3.92	4.64	158	2336.4	2.50	1.25
2	5.71	8.26	432	1431.6	1.25	0.63
3	9.13	15.38	712	816.0	0.63	0.31
MIRIS Band	**λ_1 (μm)**	**λ_2 (μm)**	**Nch (-)**	**v_av (cm-1)**	**dv_av (cm-1)**	**dv_samp (cm-1)**
1	3.70	5.32	960	2217.3	1.66	0.83
2	8.00	14.50	960	888.9	1.07	0.53

For MIRIS, we explored the following two questions. First, can we retrieve water vapor in the 5µm region rather than the 6.2-8.7µm region, and secondly can we live without the longest wavelength bands at 15µm? These two changes would allow the removal of two spectrometers, provided that the spectral range of the two remaining spectrometers is extended. Table 1 shows the two MIRIS bands selected, for a total of 1920 channels.

Temperature Sounding

Figure 1 shows the spectral range selected for temperature and water vapor sounding in the MWIR. AIRS currently uses part of this band for temperature sounding and the AIRS channels are indicated in blue. AIRS also uses the LWIR channels for cloud clearing.

As a demonstration of the ability to achieve temperature sounding in this band without any LWIR influence, an experiment was performed where we removed the LWIR channels from AIRS prior to running the temperature retrieval. The startup for the retrieval was the profile produced from the Advanced Microwave Sounding Unit (AMSU) also on Aqua. Results are shown in Figure 2. The AIRS/AMSU retrieval baseline retrieval performs the best with between 1.0 K and 1.25 K RMS difference globally compared to the European Center for Medium-Range Weather forecast (ECMWF) reanalysis. For the case with only the MWIR channels (no 15 µm channels) we see a degradation in the performance between 300 and 100 mb. Since the LWIR channels are not used in the retrieval, we expect this difference to be due to sampling biases. Finally, the microwave only (AMSU only) retrieval is also shown. The MWIR is better than the AMSU only retrieval, particularly in the lower troposphere (below 500 mb) indicating the MWIR channels are most likely sufficient where it is needed most, in the lower troposphere. This analysis does not take advantage of the neural network regression first guess that significantly improved the AIRS Version 6 retrieval accuracy, nor the slightly improved spectral resolution proposed for MIRIS in this band.

The loss of the ability to do cloud clearing (no LWIR channels) is not expected to be an issue since the higher spatial resolution proposed for this system, i.e. 1 km horizontal, will enable a significantly greater fraction of "clear" cases. Also National Weather Prediction (NWP) centers are currently not assimilating cloud cleared radiances, so the higher spatial resolution will allow more "raw" observations to be assimilated without a change in the current data assimilation system; i.e. more will pass the "clear" test.

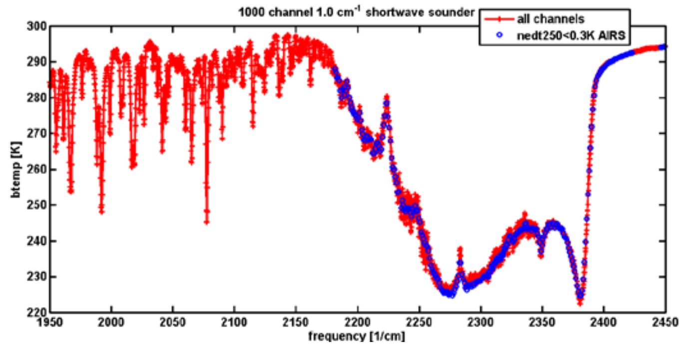


Figure 1. Spectral Range selected for MIRIS includes the full MWIR CO2 temperature sounding band used in AIRS, but extends the band (below 2150 cm^{-1}) for water vapor.

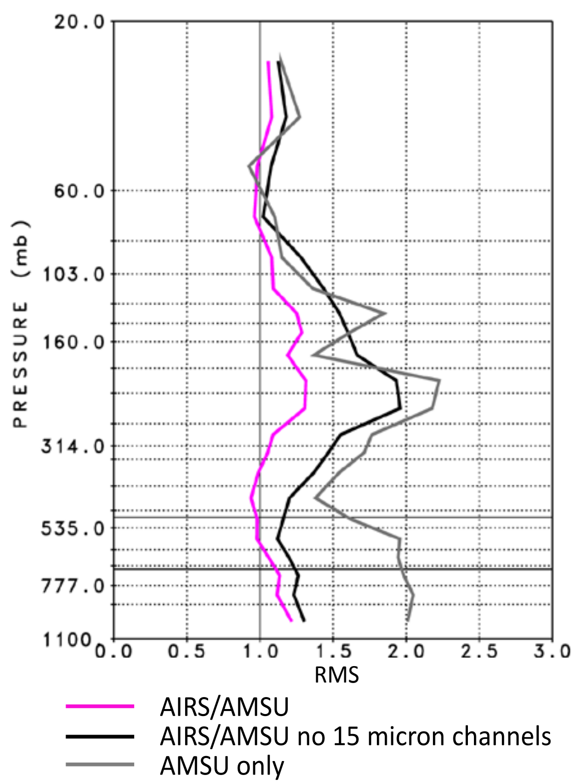


Figure 2. AIRS/AMSU Retrievals Global Cases for July 10, 2012, Layer Mean RMS Temperature Differences from ECMWF "Truth" (K)

Water Vapor Sounding

Since the AIRS and MIRIS do not use the same water vapor channels, we cannot use the AIRS to demonstrate the MIRIS capabilities. For this investigation we look at the degrees of freedom (DOF) of signal for AIRS selected channels and the MIRIS spectral region for water vapor and temperature. The analysis assumes a US Standard Tropical Atmosphere and AIRS spectral resolution for the bands identified in Table 2 for AIRS and MIRIS. For AIRS, these are the same bands used in the operational Version 6 retrieval. For MIRIS, they were defined to provide the best sensitivity in the lower troposphere.

Table 2. MIRIS and AIRS Channels used in the DOF analysis for Temperature and Water Vapor

	AIRS			MIRIS		
	Spectral region (cm^{-1})	Sampling (cm^{-1})	FWHM (cm^{-1})	Spectral region (cm^{-1})	Sampling resolution (cm^{-1})	FWHM (cm^{-1})
Temperature	662-712	0.27	0.47	2150-2280	1.0	2.0
	1239-1382	0.55	1.04			
	2358-2416	0.98	1.88			
Water Vapor	1310-1605	0.54	1.04	1880-2280	1.0	2.0
	2607-2656	1.07	2.07			

The high spectral resolution radiance and analytical Jacobians are calculated using a Radiative Transfer Algorithm (RTA) rewritten based on Line-By-Line Radiative Transfer Model (LBLRTM). It is convolved to the spectral resolution of AIRS Full Width Half Maximum (FWHM) with a Gaussian function. The signal to noise ratio (SNR) is calculated using AIRS instrument Noise Equivalent Delta Temperature (NEDT) as a function of wavenumber. The averaging kernel (A) describes the sensitivity of the estimated state to the change of the true state and it is computed with the Jacobian matrix (K), covariance matrix of measurement noise (S_n), and covariance matrix of a priori (S_a).

$$\mathbf{A} = \frac{\partial \hat{x}}{\partial x} = (\mathbf{K}^T \mathbf{S}_n^{-1} \mathbf{K} + \mathbf{S}_a^{-1})^{-1} \mathbf{K}^T \mathbf{S}_n^{-1} \mathbf{K}$$

The trace of the averaging kernel gives the number of degrees of freedom for signals (DOFs) from the retrieved variable.

Figure 3a shows the results of the analysis for water vapor and Figure 3b for temperature. We see that the sensitivity to water vapor in the lower troposphere is actually better in the MIRIS than the AIRS case, but reduced sensitivity is seen above 300 mb. Temperature sensitivity is roughly equivalent between the AIRS and MIRIS.

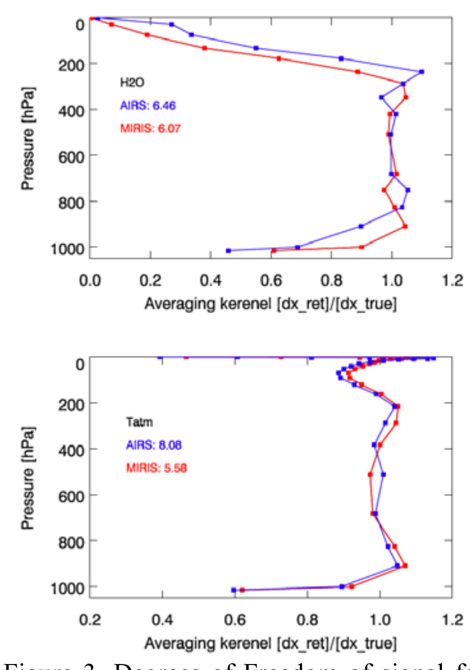


Figure 3. Degrees of Freedom of signal for the AIRS and the MIRIS for: a. (upper) water vapor, b. (lower) temperature.

2.2 Infrared Imaging

Global imaging in the infrared can be accomplished by meeting the band set defined by VIIRS. Table 3 gives the VIIRS bands and the corresponding bands covered by the MIRIS. The Vis/NIR/SWIR bands from 0.4µm – 2.25µm can be met by the PACE OCI as defined in the PACE Science Definition Team Report[17]. In some cases the OCI threshold spectral requirements do not exactly fall on the band, and fall a little short on M11 (OCI only requires 2.13µm), however this band is included in the goal requirements of the team and the option for a spectrometer allows all remaining bands to be readily synthesized.

In the infrared, the MIRIS band number 1 was extended beyond the sounding requirements to 3.7 µm to cover the lowest wavelength VIIRS band. The 3.7 µm VIIRS band is for imaging clouds and Sea Surface Temperature (SST). We also provide a second band, number 2, from 8.0-12.5 µm to cover the LWIR VIIRS bands and support IR sounding. Many of the imaging products that use the LWIR can be met using the MWIR band. This is due to the presence of "superwindow" channels that have very little water vapor absorption high radiometric accuracy and sensitivity. The Day-Night-Band (DNB) is provided in the MIRIS or OCI concepts, and it is expected to be a separate instrument if needed.

Table 3. VIIRS Bands and the bands used in MIRIS to satisfy the infrared imaging requirements.

VIIRS Band	λ (μm)	Δλ (μm)	MIRIS Band
M1	0.412	0.020	OCI
M2	0.445	0.018	OCI
M3	0.488	0.020	OCI
M4	0.555	0.020	OCI
I1	0.645	0.050	OCI
M5	0.672	0.020	OCI
M6	0.751	0.015	OCI
M7	0.865	0.039	OCI
I2	0.865	0.039	OCI
M8	1.240	0.020	OCI
M9	1.378	0.015	OCI
M10	1.610	0.060	OCI
I3	1.610	0.060	OCI
M11	2.250	0.050	OCI
M12	3.700	0.180	1
I4	3.740	0.380	1
M13	4.050	0.160	1
M14	8.550	0.300	2
M15	10.800	1.000	2
M16	12.010	0.950	2
I5	11.450	1.900	2
DNB	0.700	0.400	n/a

We include channels between 12.5 and 14.5 μm where the detector cuts off to improve sounding capability, however, we should revisit this as a shorter cutoff wavelength will relax detector cooling requirements.

3. PERFORMANCE

A system performance model was developed that includes parameters for the scanner, telescope, spectrometers and focal plane assemblies. The parameters were adjusted for smallest aperture while employing new designs based on the SIRAS wide field optical system and focal plane assemblies currently available from industry. The parameters were used in various models to assess the instrument spectral, spatial and radiometric performance.

3.1 Spectral Resolution and Range

We discussed the spectral range in the prior section and have shown that the OCI covers the Vis/NIR/SWIR and MIRIS covers the entire VIIRS infrared range. MIRIS also covers most of the range of CrIS and AIRS (see table 1). Spectral resolution is comparable or better in the OCI and MIRIS system.

3.2 Spatial Resolution and Coverage

The driving spatial requirements for the combined imager sounder is the need to match the VIIRS constant high spatial resolution. Table 4 shows the spatial resolution requirements for VIIRS both at nadir and at the end of scan. The VIIRS "M" bands use a nominal pixel at nadir of 0.742 x 0.259 km in the track and scan directions respectively. This enables a pixel aggregation scheme that provides near constant resolution (within 2x) across all scan angles. The imagery, "I", bands have 0.371 x 0.129 km spatial resolution and aggregate 3 pixels in the scan direction at nadir, resulting in 0.371 x 0.387 km spatial resolution. The pixel aggregation scheme for the "I" bands is similar to the "M".

The OCI/A option of the PACE mission provides 250 m spatial resolution that can be used to provide a constant resolution through aggregation, almost exactly like the VIIRS "M" bands. The OCI/A system cannot meet the requirements of the "I" bands beyond a scan angle of 48.7 degrees. The MIRIS requirements also call for 250 m pixels allowing a similar aggregation scheme. However, we expect MIRIS to require a longer dwell time (due to the larger number of channels per band being read out) and allow a 500 m along-scan integration blur to relax requirements overall in the infrared. This will result in spatial noncompliance for the "M" bands in the infrared beyond a scan angle of 48.7 degrees, and the imagery "I" bands beyond 34.9 degrees. These results are summarized in Table 5. We believe this performance will be satisfactory for the vast majority of applications.

Table 5. Compliance to VIIRS requirements for spatial resolution not met at all scan angles

VIIRS Band	OCI/A	MIRIS
"M" Bands	All Angles	to 48.7°
"I" Bands	to 48.7°	to 34.9°

Hyperspectral sounding can be achieved with the MIRIS at the full spatial resolution of the instrument (250 m x 500 m), however, the NEdT for an individual spectral channel will be too low at this spatial resolution for adequate temperature and water vapor sounding. We suggest that the atmospheric sounding product radiances be at least 2km to achieve adequate NEdT. For this reason, the predicted NEdT for sounding channels is quoted at 2km in the next section.

Table 4. Spatial resolution requirements for VIIRS and compliance by the OCI/A and MIRIS instruments.

				VIIRS			OCI/A + MIRIS			
		Band No.	Wavelength (um)	Horizontal Sample Interval (km DownTrack x CrossTrack)		Driving EDRs	Wavelength (um)	Horiz Sample Interval (km Downtrack x Crosstrack)		**Compliance with VIIRS**
				Nadir	End of Scan			**Nadir**	**End of Scan**	
VIS/NIR FPA	Silicon PIN Diodes	M1	0.412	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	0.335 - 0.945	0.750 x 0.250	1.7 x 1.7	□
		M2	0.445	0.742 x 0.259	1.60 x 1.58		0.335 - 0.945	0.750 x 0.250	1.7 x 1.7	□
		M3	0.488	0.742 x 0.259	1.60 x 1.58		0.335 - 0.945	0.750 x 0.250	1.7 x 1.7	□
		M4	0.555	0.742 x 0.259	1.60 x 1.58		0.335 - 0.945	0.750 x 0.250	1.7 x 1.7	□
		I1	0.640	0.371 x 0.387	0.80 x 0.879	Imagery	0.335 - 0.945	0.250 x 0.250	0.602 x1.75	ü - Compliant up to 48.7 deg
		M5	0.672	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	0.335 - 0.945	0.750 x 0.250	1.7 x 1.7	□
		M6	0.746	0.742 x 0.776	1.60 x 1.58	Atmospheric Correction	0.335 - 0.945	0.750 x 0.750	1.7 x 1.7	□
		I2	0.865	0.371 x 0.387	0.80 x 0.879	NDVI	0.335 - 0.945	0.250 x 0.250	0.602 x1.75	ü - Compliant up to 48.7 deg
		M7	0.865	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	0.335 - 0.945	0.750 x 0.250	1.7 x 1.7	□
CCD		DNB	0.700	0.742 x 0.742	0.742 x 0.742	Imagery				□
S/MWIR	PV HgCdTe (HCT)	M8	1.240	0.742 x 0.776	1.60 x 1.58	Cloud Particle Size	1.10 - 2.26	0.750 x 0.750	1.7 x 1.7	□
		M9	1.378	0.742 x 0.776	1.60 x 1.58	Cirrrus/Cloud cover	1.10 - 2.26	0.750 x 0.750	1.7 x 1.7	□
		I3	1.610	0.371 x 0.387	0.80 x 0.879	Binary Snow Map	1.10 - 2.26	0.250 x 0.250	0.602 x1.75	ü - Compliant up to 48.7 deg
		M10	1.610	0.742 x 0.776	1.60 x 1.58	Snow Fraction	1.10 - 2.26	0.750 x 0.750	1.7 x 1.7	□
		M11	2.250	0.742 x 0.776	1.60 x 1.58	Clouds	1.10 - 2.26	0.750 x 0.750	1.7 x 1.7	□
		I4	3.740	0.371 x 0.387	0.80 x 0.879	Imagery Clouds	1.10 - 2.26	0.250 x 0.500	0.60 x 3.3	ü - Compliant up to34.9 deg (0.349
		M12	3.700	0.742 x 0.776	1.60 x 1.58	SST	3.76 - 5.13	0.750 x 0.500	1.7 x 3.3	ü - Compliant up to 48.7 deg
		M13	4.050	0.742 x 0.259	1.60 x 1.58	SST / Fires	3.76 - 5.13	0.750 x 0.500	1.7 x 3.3	ü - Compliant up to 48.7 deg
LWIR	PV HCT	M14	8.550	0.742 x 0.776	1.60 x 1.58	Cloud Top Properties	8.0 - 15.4	0.750 x 0.500	1.7 x 3.3	ü - Compliant up to 48.7 deg
		M15	10.763	0.742 x 0.776	1.60 x 1.58	SST	8.0 - 15.4	0.750 x 0.500	1.7 x 3.3	ü - Compliant up to 48.7 deg
		I5	11.450	0.371 x 0.387	0.80 x 0.879	Imagery Clouds	8.0 - 15.4	0.250 x 0.500	0.60 x 3.3	ü - Compliant up to34.9 deg (0.349
		M16	12.013	0.742 x 0.776	1.60 x 1.58	SST	8.0 - 15.4	0.750 x 0.500	1.7 x 3.3	ü - Compliant up to 48.7 deg

3.3 Radiometric Sensitivity (NEdT) and Dynamic Range

A radiometric performance model was developed for MIRIS that provides the NEdT for two configurations: 1) Sounding: full spectral resolution aggregated to 2 km spatial resolution (Figure 4), and 2) Imaging: full spatial resolution aggregated to the VIIRS bands (Figure 5). The MIRIS sounding performance is comparable to AIRS for most channels, but we see the degradation at the longest wavelength (beyond 13 µm). The MIRIS performance to this level requires cooling the LWIR detectors to 55K, since the long-wavelength cutoff produces excess dark current at the shorter wavelengths in the band. No attempt was made to recover the performance since we have shown the MWIR band can achieve adequate sounding without these channels.

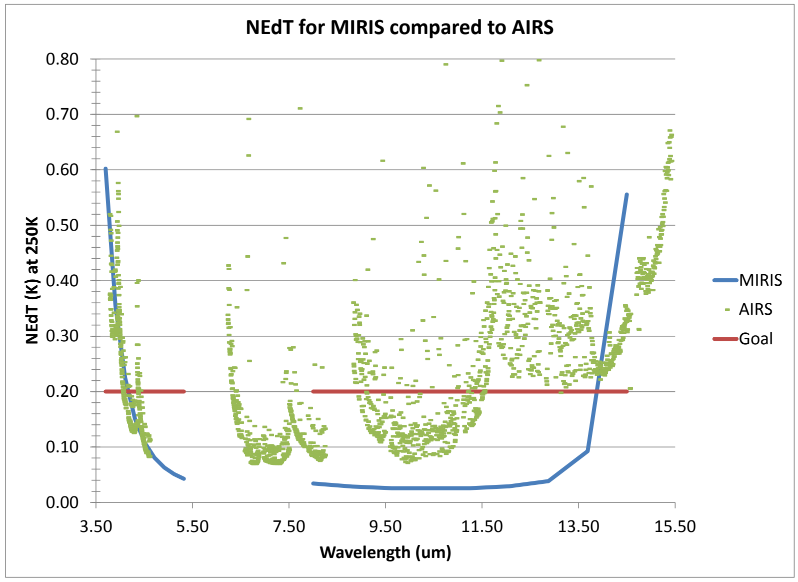


Figure 4. Sounding Channels NEdT. MIRIS full spectral resolution at 2km spatial resolution

Figure 5 shows the Imaging NEdT. In this estimate, the VIIRS channels are synthesized from the MIRIS channels. VIIRS footprints are also aggregated from the MIRIS footprints. NEdT is quoted for the full synthesized VIIRS band for the end of scan aggregation configuration. Actual performance of the VIIRS data products will be much better with the hyperspectral channels since errors in atmospheric correction will be greatly reduced.

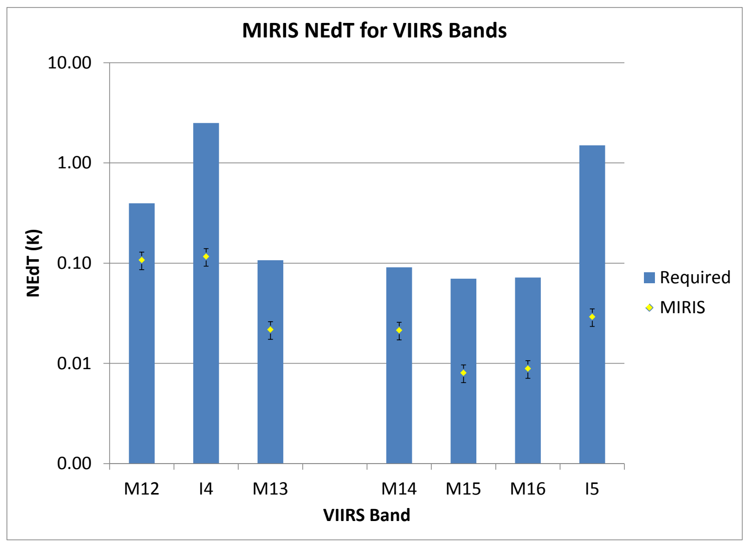


Figure 5. NEdT for MIRIS Imaging Channels synthesized by aggregating the full spectral resolution. NEdT at full spatial resolution of the instrument.

4. APPROACH

A preliminary instrument design was developed to enable sizing of resource requirements of the system. We attempted to use as much commercial technology as possible (detectors and coolers), as well as proven optics technology (SIRAS IIP spectrometers). The remaining systems (scanner, mechanical system, electronics, etc.) assume standard spaceflight qualified implementation as available on numerous prior systems.

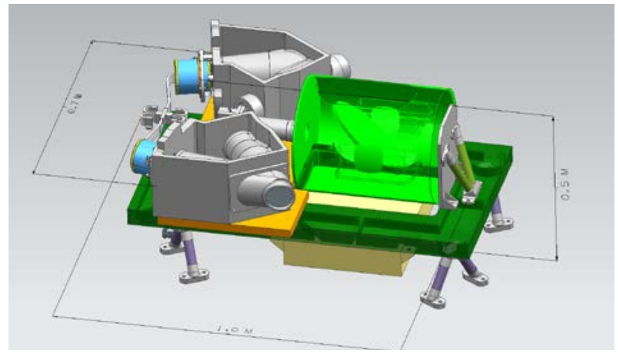
4.1 System Concept

The design concept, shown in Figure 6, includes a single scanner mounted on a 2-axis gimbal allowing along-track scanning as well as the standard cross-track scanning. This allows pointing and tracking a single target for improved sensitivity, or computing winds by tracking changes in water vapor fields. The energy from the scanner is collected via a single 50 mm Effective Pupil Diameter (EPD) reflective telescope and directed to two individual grating spectrometers (corresponding to the two spectral bands) via dichroic beamsplitters. The grating spectrometers disperse the energy into the individual spectral channels at the detector array. Spectrometer designs have been developed and show no insurmountable challenges. The system includes large format Teledyne CHROMA commercial detector arrays (480 x 640), 2 per band, and active cooling using the NGC Pulse Tube Cooler (of AIRS Heritage). Passive radiators are not shown but place additional requirements on the orientation of the spacecraft. A sun synchronous orbit is required with a clear view to space as is currently available for the legacy instruments. Resource requirements for MIRIS are given in Table 6.

Table 6. Estimated Resource Requirements for MIRIS

Parameter	Value
Size	1.0 x 0.7 x 0.5 m
Mass	100 kg
Power	130 W
Data Rate	< 20 Mbps

Figure 6. MIRIS Instrument Concept includes a 2-axis gimbal scan mirror, telescope, 2 grating spectrometers, 2 FPA's and an active cryocooler.



4.2 Technology Readiness Level (TRL)

All subsystems in the MIRIS are at TRL 6 or higher at this time. Similar scanners have been built by BEI for flight on MODIS and AIRS with only one axis. Two axis gimbaled systems have been flown, but in different configurations. All reflective telescopes have flown on numerous NASA missions, and the spectrometers have been demonstrated by Ball Aerospace in the SIRAS IIP[14,15]. The CHROMA focal plane assembly has not flown, at the time of this writing but is proposed for several other space missions and will be at least TRL 8 by the time MIRIS flies. The NGC cryocoolers will fly on GOES-R.

All systems are straightforward in the MIRIS design, however the greatest challenge comes in achieving sufficient performance in the longest wavelengths due to the limitations in the cutoff wavelength of HgCdTe. The long cutoff wavelength results in more noise that contributes to reduced performance across the band.

5. CONCLUSIONS

Requirements have been developed for a Moderate resolution Infrared Imaging Sounder (MIRIS) to provide imaging and sounding data for operational weather prediction, Earth science, and applications. Employing NASA's OCI/A instrument on the proposed PACE mission (enhanced version with 250 m spatial resolution), enables the vast majority the VIIRS Vis/NIR/SWIR requirements to be satisfied leaving the MIRIS to focus on the combined CrIS and VIIRS infrared requirements. The new requirements identified here reduce constraints on the instrument enabling only two spectrometers to meet the majority of the requirements. This is achieved by performing temperature and water vapor sounding in the MWIR band, and imaging in the LWIR band. We also reduced the long-wave cutoff requirements to a best-effort beyond 12.5 µm since the sounding channels that exist in this region of the spectrum are supplanted by those in the MWIR. Requirements that are not satisfied by the current systems include the Day/Night Band and constant resolution beyond 48.7º for Vis/NIR/SWIR imaging bands and infrared "M" bands and 34.9º for the infrared imaging, "I" bands. The overall NEdT looks good compared to AIRS except beyond 13.5 µm, and they meet all the VIIRS requirements when these bands are synthesized. More important than meeting the majority of current requirements is that the MIRIS provides hyperspectral imaging that can be used for more accurate products and calibration. Improved accuracy comes from less interference from atmospheric absorption features and improved calibration accuracy comes from the ability to use the atmosphere to calibrate the spectral centers of the bands. Finally, improved forecast accuracy is expected form the higher spatial resolution atmospheric sounding due to the ability to sound closer to clouds while still maintaining clear and to capture fine scale gradients in weather patterns for validation and initialization of the next generation of high spatial resolution sounders. MIRIS resource requirements are modest and the Technology Readiness Level is high leading to the expectation that the cost and risk of MIRIS will be reasonable.

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