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N94-22298

INTERCOMPARISON OF MAS, AVIRIS, AND HIS DATA FROM FIRE CIRRUS II

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Introduction

The NASA ER-2 flight on December 5th, 1991 is unique among the FIRE Cirrus II missions in that data were acquired simultaneously by the MODIS Airborne Simulator (MAS), the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), and the High Resolution Interferometer Sounder (HIS). These data represent a unique source of information about the spatial and spectral properties of cirrus clouds. The MAS is a new instrument which will aid in defining algorithms and building an understanding of the ability of the Moderate Resolution Imaging Spectroradiometer (MODIS) to remotely sense atmospheric conditions for assessing global change. In order to establish confidence in the absolute calibration accuracy of the MAS radiances, an inter-comparison of MAS radiances with AVIRIS and HIS has been undertaken.

The MAS is a scanning spectrometer with 50 spectral channels in the wavelength range 0.55 to 14.3 microns. During FIRE Cirrus II a set of 11 of these spectral channels was recorded in flight at 8 bits per channel (visible/near-IR) and 10 bits per channel (IR). The scanner views a swath of approximately 38 kilometers across track, and records 716 earth view pixels per scan (6.25 scans per second) with a 2.5 milliradian instantaneous field of view. Gyroscopic roll correction is used to stabilize the viewing geometry. Calibration of the visible/near-IR channels is done using integrating sphere sources on the ground before and after flight missions. Calibration of the IR channels is done using two onboard blackbody sources. A key reason for comparing MAS data to AVIRIS and HIS data is the determination of the radiometric accuracy of the MAS visible/near-IR and IR channels.

The AVIRIS is an imaging spectrometer with 224 spectral channels in the wavelength range 0.4 to 2.5 microns. The scanner views a swath of approximately 11 kilometers across track, and records 614 pixels per scan (12 scans per second) with a 1.0 milliradian instantaneous field of view. Data are digitized at 10 bits per pixel. Calibration is done using an integrating sphere on the ground, and is monitored inflight by a reference lamp source. Absolute calibration accuracy is better than 7%, and relative calibration accuracy is better than 2%.

The HIS is a nadir viewing IR interferometer with $\approx$ 2000 spectral channels in the wavelength range 3.7 to 16.7 microns and a 100 milliradian field of view. Radiance spectra are produced using calibration information from 2 onboard blackbody sources. Absolute calibration accuracy is better than 1 K and relative calibration accuracy is on the order of 0.1 K.

MAS and AVIRIS intercomparison

At the time of the FIRE Cirrus 1991 deployment, the MAS had 5 channels in the visible/near-IR region with central wavelengths at 0.681, 1.617, 1.933, 2.088, and 2.139 microns. At this time the AVIRIS was experiencing noise problems in some of the longer wavelength channels, and thus only the data from MAS channels 2 (0.681 microns) and 3 (1.617 microns) could be used in the comparison. The MAS and AVIRIS scenes were examined to find areas of overlap, since the AVIRIS does not record continuously during flight. Within regions of overlapping imagery, the MAS scenes were examined to find small areas of uniform brightness. Once such areas were located, a 10x10 pixel box was fitted over the region and the average radiance was computed in channels 2 and 3. The corresponding area was then located on the AVIRIS imagery, and a box of AVIRIS pixels was marked off to cover the same region as the MAS 10x10 pixel box. An average AVIRIS spectrum was then computed over the box. This average spectrum was convolved with the MAS spectral response curves for channels 2 and 3, and the corresponding radiances were computed. It should be noted that while a laboratory measured spectral response was available for MAS channel 2, none was available for channel 3. Thus using the predicted central wavelength and bandwidth at 50% response, a Gaussian spectral response was computed. A table of the radiance comparisons for 6 cases is presented below. All of these were cloud features over the Gulf of Mexico within ± 10 minutes of 1600Z. ER-2 takeoff was at 1430Z.

Case number, Cloud type	Channel 2 (0.681 micron) radiance ($W\ m^{-2}\ sr^{-1}\ \mu m^{-1}$)			Channel 3 (1.617 micron) radiance ($W\ m^{-2}\ sr^{-1}\ \mu m^{-1}$)		
	MAS	AVIRIS	Δ%	MAS	AVIRIS	Δ%
1, thick cirrus	152.56	148.92	2.4	11.77	12.97	-10.2
2, thin cirrus	35.74	33.30	7.3	2.90	2.74	5.8
3, thin cirrus	25.52	26.68	-4.3	2.14	2.43	-13.5
4, thin cirrus	25.01	25.41	-1.6	2.20	2.18	0.9
5, convective	153.66	149.93	2.5	17.72	20.30	-14.5
6, thin cirrus	20.73	20.39	1.7	1.31	1.28	2.3

While 6 cases is not a large sample, it can be seen that the MAS is providing radiances which are in general agreement with the AVIRIS. The MAS is calibrated on the ground using an integrating sphere, and does not have an in-flight visible/near-IR calibration capability. Thus the demonstration that MAS radiances are close to AVIRIS radiances gives some measure of confidence in the MAS in-flight calibration. However, some calibration uncertainties are still under investigation. Cold chamber testing of the MAS in February 1992 showed decreasing sensitivity with decreasing temperature in channels 3, 4, 5, and 6. For example in channel 3, an approximately linear decrease in instrument sensitivity of 30% was observed when the chamber was cooled from 20° C to -35° C. It is not yet clear whether this effect occurred during flight of the MAS. Temperature sensors attached to the MAS during the FIRE deployment showed a gradual decrease in head temperature over the course of the flight to a minimum of -30 to -35° C. However this minimum temperature is not reached until the end of a flight, which may be 4 to 5 hours long. The comparisons presented here are at 1.5 hours after ER-2 takeoff, and therefore do not represent the coldest instrument temperature. In future work, MAS and AVIRIS radiances will be compared over the course of the complete ER-2 flight on December 5th, to determine whether the sensitivity decrease observed in the cold chamber is observed in flight. It should be noted that after modifications to the MAS, cold chamber tests in May and August 1992 showed a reduction in temperature sensitivity, however this has not been verified in-flight. Data from future MAS and AVIRIS co-flights (SCAR-A July 1993) will be used to further investigate the calibration of the MAS visible/near-IR channels.

MAS and HIS comparison

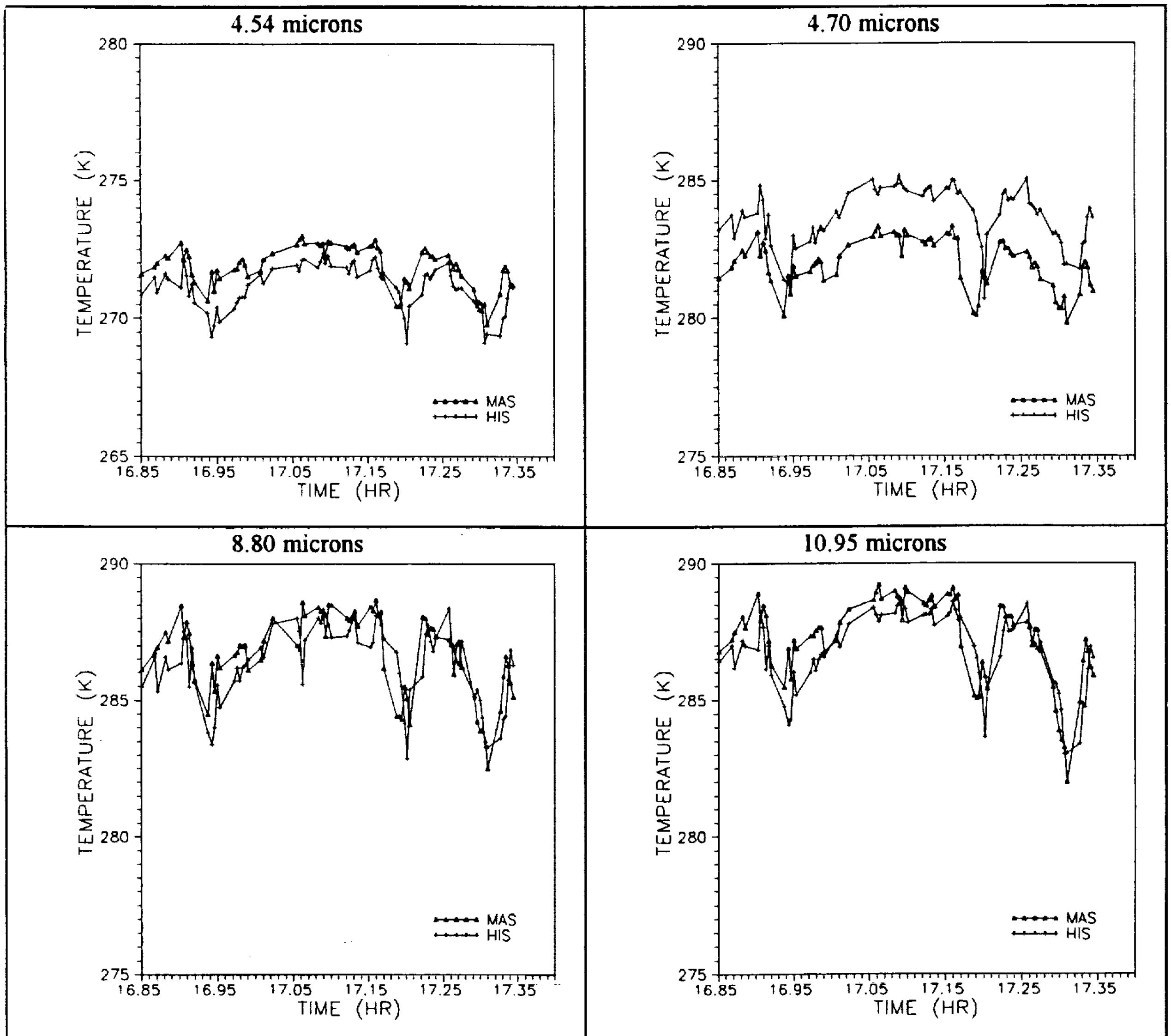
At the time of the FIRE Cirrus 1991 deployment, the MAS had 6 channels in the IR region with central wavelengths at 3.75, 4.54, 4.70, 8.80, 10.95, and 11.95 microns. The HIS acquired data in all these spectral regions except 3.75 microns. Therefore to examine the calibration of the MAS, co-located MAS and HIS radiances were compared. The HIS data used were apodized radiance spectra, averaged over two scan directions. This gives a footprint of approximately 3.2 km along track and 2 km across track. This corresponds to a MAS scan region of approximately 91 pixels along track and 43 pixels across track. Due to an offset between the MAS and HIS clocks, it was necessary to manually match the HIS along track data to the MAS data. It is estimated that this was done to around ± 5 seconds, which corresponds to ± 31 MAS scanlines. Thus some offset may still remain between the HIS footprints and the averaged MAS footprints. Once the co-located footprints were found, the HIS radiance spectrum was convolved with the spectral response curve for each MAS IR channel to produce an equivalent radiance, which was then converted to brightness temperature. Average radiances and brightness temperatures were computed over the corresponding 91x43 pixel MAS footprints. It should be noted that while a laboratory measured spectral response was available for MAS channel 11, none was available for channels 8, 9, 10, and 12. Thus using the predicted central wavelength and bandwidth at 50% response, Gaussian spectral responses were computed. A table of comparison results is shown below. The 76 co-located footprints were over land on a transit leg from the Gulf of Mexico to Coffeyville KS. Most of the flight track was over clear skies, however patchy cirrus was present in places.

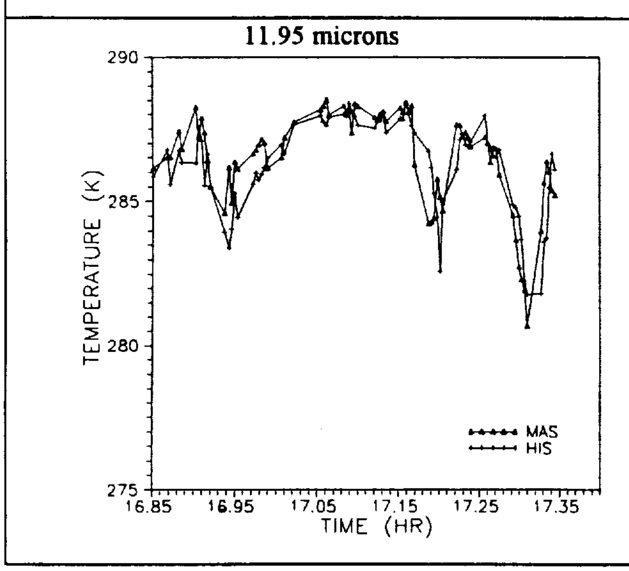
MAS IR Absolute Accuracy (Compared to co-located HIS fields of view) 76 mostly clear sky 91x43 MAS pixel averages over land, 1651Z to 1721Z, 5-DEC-91			
Channel	Wavelength (microns)	MAS-HIS Average (K)	MAS-HIS RMS (K)
9	4.54	0.77	0.58
8	4.70	-1.68	0.75
10	8.80	0.37	1.07
11	10.95	0.51	0.91
12	11.95	0.27	1.01

Plots of the along track comparison of MAS and HIS footprints are shown overleaf. Although the RMS of the average difference is quite large with respect to the average difference itself, it is clear that reasonable brightness temperatures are derived from the MAS. Several sources of noise cause the RMS to be large with respect to the mean. First, the previously mentioned collocation error of ± 5 seconds means that over rapidly varying scenes, the HIS and MAS may view significantly different average temperatures. Second, the MAS data contain noise introduced by the detector electronics, and the aircraft power system. An estimate of the noise in the MAS IR imagery was obtained by computing the average and RMS values of a block of 50x50 pixels over a region of cloud-free ocean. From the RMS radiance values, the noise equivalent delta temperature was computed. The results for all IR channels are shown below.

MAS IR Relative Accuracy (Noise Equivalent Delta Temperature) Clear sky 50x50 MAS pixel average over water, scanline 47951, 1634Z, 5-DEC-91				
Channel	Wavelength (microns)	Bits recorded	Average Temperature (K)	NEDT (K)
7	3.75	8	289.19	1.62
9	4.54	10	274.25	0.99
8	4.70	8	284.88	0.70
10	8.80	10	290.06	0.32
11	10.95	10	291.12	0.43
12	11.95	10	289.89	0.82

The relatively large negative bias (MAS colder than HIS) in channel 8 suggests that the spectral response may not be accurately approximated by a Gaussian, or that its position is slightly different than the estimated central wavelength. It is possible that the center of the spectral response may shift during flight. The comparisons shown above were all within the space of 30 minutes, so variation throughout the flight has not been sampled. It is possible that the biases shown above drift with time over the course of a flight, as the instrument temperature changes. This will be examined in future work.





MAS and HIS along track co-located footprints,
FIRE Cirrus II, December 5th, 1991.
MAS data are averaged over 91x43 pixels,
HIS data are averaged over two earth views.