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CIMSS FIRE RESEARCH ACTIVITIES

W. L. Smith, S. A. Ackerman R. O. Knuteson, X. L. Ma, and H. E. Revercomb,
Cooperative Institute for Meteorological Satellite Studies

ABSTRACT

This paper presents an overview of the Cooperative Institute for Meteorological Satellite Studies' FIRE research activities. The paper focuses on analysis of the High-resolution Interferometer Sounder (HIS) made from the ER-2 as well as ground based measurements made by the Atmospheric Emitted Radiance Interferometer (AERI) prototype. Details are covered in companion papers.

ER-2 HIS OBSERVATIONS

The HIS aircraft instrument (Smith et al 1989) is a Michelson interferometer with a spectral resolving power ($\lambda/\Delta\lambda$) of approximately 2000 covering the spectral range from approximately 3.5-16.7 μ m. The HIS spectra have an unapodized resolution of approximately 0.35 cm^{-1} from 600-1100 cm^{-1}, and 0.7 cm^{-1} resolution from 1100-2700 cm^{-1}. A cycle of HIS interferograms consists of four cold blackbody views, four hot blackbody views and 12 earth views. The on board high emissivity, temperature controlled reference blackbody views are used for the calibration of the earth views. The HIS has a noise equivalent temperature and reproducibility of about 0.1-0.2°C over much of the spectrum (Revercomb *et al.*, 1988). Recent upgrades to the HIS have significantly improved instrument performance in the 3.5-5.0 μm spectral region.

The HIS flew aboard the NASA ER-2 during FIRE Phase I (Oct-Nov 1986). The most significant result of these observation was that cirrus clouds do not emit radiation like blackbodies, irregardless fo their optical thickness. Figure 1 has become an historical example of the FIRE I HIS finding that the spectral variation of the radiating temperature of cirrus has a large spectral variation across the climatolically important 8-12 μm "window" region of the thermal infrared.

Another very important finding from FIRE-I HIS radiance spectra was that the water phase of clouds could be diagnosed from simultaneous infraed window measurements at 8, 11 and 12 μm (Smith et al 1988, Ackerman et al 1990). Figure 2 shows a time sequence of 8.3, 11.1 and 12.0 μm HIS brightness temperature together with simultaneous Lidar cloud backscatter observations with the CALS (Spinhirne, 1990). It can be seen that for the case of ice particle cirrus (high altitude backscatter) the 8.3 μm brightness temperature is significantly larger than the 11 and 12 μm brightness temperature whereas for the case of liquid water droplet lower clouds (low altitude backscatter) both the 8 and 11 μm brightness temperature are larger than 12 μm. These results correspond to the different spectral absorption properteis of ice and water (Figure 3).

For FIRE II, HIS data analysis has focused on the determination of the radiative and microphysical properties of cirrus clouds. Table 1 below lists the days and times of available HIS data during FIRE II. Our research objectives under the FIRE Phase II program include: 1) to improve our understanding of the relationship between the microphysical and radiative properties of cirrus clouds; 2) to quantify the capabilities and limitations of various cirrus cloud satellite retrieval techniques; and 3) to improve our capabilities of describing cirrus cloud properties utilizing passive radiometric observations. Since the last FIRE team meeting, we have focused our activities on objectives 1) and 3).

A doubling/adding model has been developed to simulate high-spectral resolution measurements from ground and ER-2 aircraft. This model has been used to study the sensitivity of the spectral observations to various cloud conditions and then to develop and test cloud retrieval algorithms using such observations (Smith et al 1990,1992, 1993). A time section of cloud ice particle size and ice water content deduced from HIS spectra from the ER-2 aircraft are shown in Figure 4. The cloud altitude and thickness were set at the height levels observed by the CALS. The cloud ice water content varies between 2.3 g m^{-3} and effective radius is about 20 μm. Cloud heights are accurately determined using HIS carbon kioxide channel information even for relatively low effective cloud emissivites. Improvements in cloud properties retrieval from HIS data by incorporating the 3.7-4.0 μm window and the 4.3 CO_2 radiances are now being investigated.

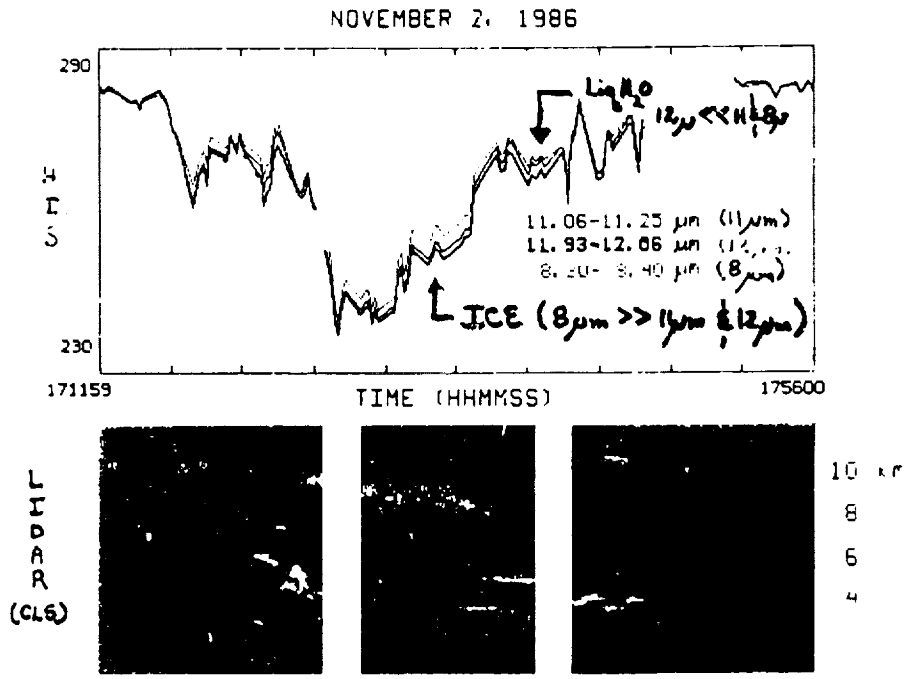

Figure 2. Time series plot of 8, 11 and 12 m brightness temperatures. CALS lidar image is displayed below.

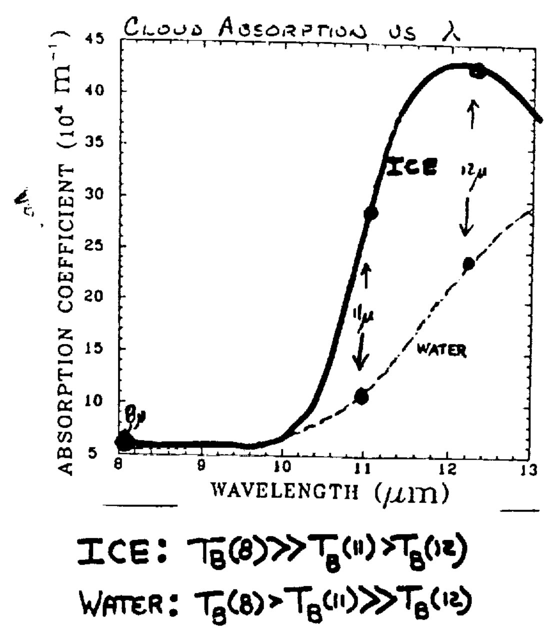

Figure 3. Absorption Coefficient as a function of wavelength

TABLE 1. SUMMARY OF HIS FLIGHT DATA

DATE	TARGET AREA	TIME (UTC)	HIS DATA STUDY OBJECTIVE
14 Nov 91	Kansas	14:01-18:00	Cirrus
18 Nov 91	Kansas	20:56-23:30	Clear sky
22 Nov 91	Kansas	18:30-20:30	Cirrus
24 Nov 91	Gulf Mex	17:00-21:10	Cirrus
25 Nov 91	Oklahoma	16:00-20:00	Cirrus
26 Nov 91	Kansas	15:00-17:50	Cirrus
3 Dec 91	Gulf Mex	15:30-18:00	Cirrus
4 Dec 91	Gulf Mex	18:30-20:30	Corpus Christi / Gulf of Mexico
5 Dec 91	Kansas	15:00-19:00	Cirrus

AERI OBSERVATIONS

The AERI instrument is a goundbased HIS system for the accurate and continuous measurement of downwelling infrared radiation from the atmosphere. The observed spectra are being used for many diverse functions, including identification and elimination of absolute errors in calculated spectra for known atmospheric states; evaluation and improvement of cloud radiation calculations; characterization of the distribution and evolution of effective cloud radiative properties; and studies of the state parameter changes associated with cloud formation, evolution, and dissipation. Table 2. is a summary of when the AERI prototype was operational during the DOE Spectral Radiance Experiment (SPECTRE) in association with FIRE II, conducted in Coffeyville, Kansas in the Fall of 1991. Observations of the atmosphere were collected approximately every 10 minutes.

Examples of cloudy brightness temperature spectra during FIRE II are shown in Figure 5. As found with HIS aircraft observations, clouds do not behave as "blackbodies" for which the brightness temperature would be constant in the regions between absorption lines in the atmospheric window between 8 and 13 μm (770-1250 cm^{-1}). The low cloud spectrum in the figure is close to that of a blackbody cloud, but the middle cloud shows major deviations from that simple behavior. The deviations from blackbody behavior are being used to estimate cloud base microphysical properties in much the same way cloud top microphysical propeties are being estimated from ER-2 HIS spectra (Smith, et al., 1993).

The AERI data have been used to assess the capabilities of radiative transfer model results, analyze the evolution of the boundary layer, and retrieve cloud properties. These applications are discussed in a companion paper.

FUTURE ACTIVITIES

Ground-based interferometer observations, at a resolution similar to the aircraft HIS, were collected at Coffeyville KS as part of FIRE II and SPECTRE. ER-2 over-flights of the site will enable assessment of the spectral infrared effects of clouds on the radiance distribution at the ground and at the top of the atmosphere. Cloud base properties will also be derived from the ground-based interferometer for comparison with the ER-2 based derived cloud top properties. This study is crucial for the characterization of the downwelling radiance of a cloud, based on satellite observations of the upwelling radiance as needed for use in global climate studies.

Upgrades to the HIS prior to the FIRE II field experiment improved instrument performance in the 2000-2700 cm^{-1} regime. This spectral region is also measured by the AERI. The 3.7 μm region has been employed in cloud retrieval techniques applicable to satellite observations. Radiance in the 3.5-4.6 μm region are sensitive to the particle size, shape and water phase of the cloud. We plan to enhance our previously developed capabilities of inferring cloud microphysical characteristics from the 8-12 μm spectral region using radiance from the 3.5-4.5 μm spectral region. Inferences of the cloud particle phase and effective size will be based on the spectral variability in the 3.5- 4 μm and 8-12 μm regions.

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Table 2. WISCONSIN AERI INSTRUMENT OPERATIONS

LOCATION: COFFEYVILLE, KANSAS

YEAR: 1991

REMARKS: (1) Observations are at 10 minute intervals betweenstated START and END times. (2) The letter H indicates that the ER-2 HIS was overhead. (3) OP # refers to an AERI operating period.

OP #	DATE	TIME PERIOD	CONDITIONS FROM VISUAL OBS
1	11 NOV	17:06 - 17:30	low overcast
2	12 NOV	23:26 - 02:29	cirrus
	13 NOV	02:53 - 04:28	cirrus/clear
3	13 NOV	18:18 - 01:26	cirrus
	14 NOV	02:13 - 03:41	thin cirrus
4	17 NOV	17:58 - 21:12	mixed cirrus to clear
	18 NOV	01:29 - 24:00	clear
	19 NOV	00:00 - 05:57	clear/cirrus/low thick cloud
5	20 NOV	17:20 - 23:33	clear
	21 NOV	00:12 - 24:00	clear
	22 NOV	00:00 - 19:07	cirrus/clear/rain
6	23 NOV	16:28 - 24:00	clear/mixed/overcast
	24 NOV	00:47 - 23:29	overcast/clear
	25 NOV	00:37 - 05:48	overcast
7	25 NOV	16:19 - 23:52	alto-cumulus/scatter cirrus
	26 NOV	00:29 - 24:00	clear/cirrus/mixed
8	27 NOV	14:01 - 17:21	low cloud
9	28 NOV	14:40 - 22:35	cirrus/overcast stratus
10	29 NOV	15:00 - 24:00	overcast/clear
	30 NOV	00:00 - 17:34	clear/overcast
11	03 DEC	00:25 - 23:08	overcast/ clear/ cold
	04 DEC	23:55 - 06:41	clear
12	04 DEC	17:16 - 24:36	clear/ aerosol
	05 DEC	01:23 - 24:00	clear/cirrus
	06 DEC	00:00 - 05:31	thin cirrus
13	06 DEC	14:52 - 20:33	mixed cirrus/alto cu
	07 DEC	00:54 - 05:52	clear/ aerosol/low cloud
14	07 DEC	14:49 - 21:23	low overcast/broken low

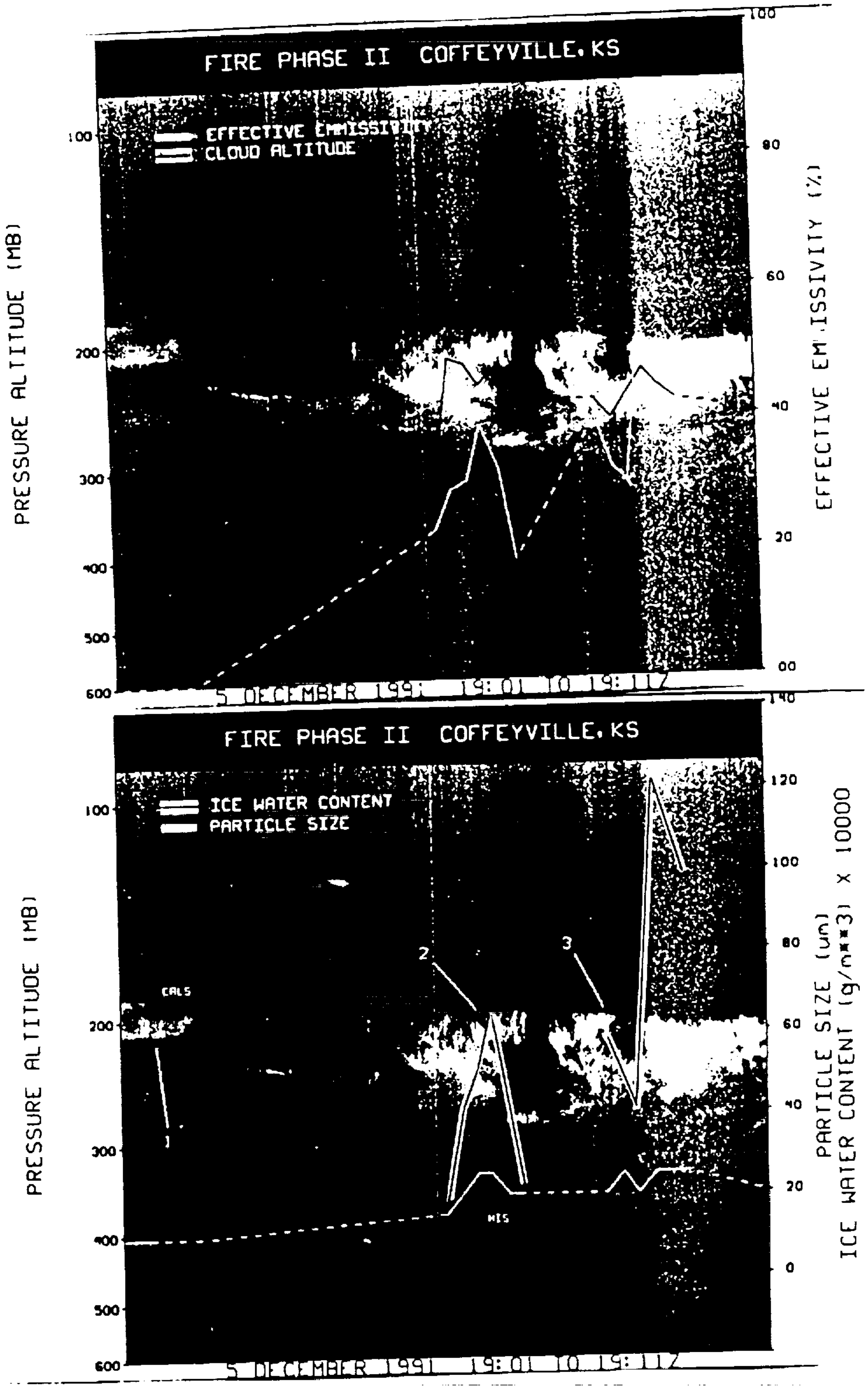

Figure 4. HIS observation near Coffeyville KS on Dec 5. 1991. (a) Cirrus ice water content and effective particle size and (b) deduced cloud altitude and effective emissivity

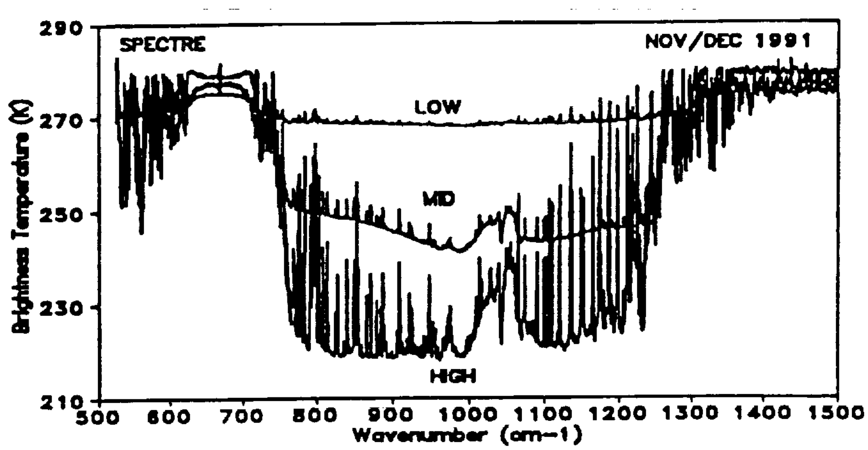

Figure 5. AERI measurements of the downwelling spectra of clouds showing deviations from black body emission.