FINAL REPORT

University of Wisconsin - Madison SSEC/CIMSS
Sub-contract

To The

University of Maryland
Baltimore County (UMBC)

A Climatology of Tropospheric CO over the Central and Southeastern United States and the Southwestern Pacific Ocean Derived from Space, Air, and Ground-based Infrared Interferometer Data

NRA-97-MTPE-07

31 March 2002

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Introduction

This report is submitted in completion of the subcontract from the University of Wisconsin – Madison Space Science and Engineering Center (UW-SSEC) to the University of Maryland Baltimore County (UMBC) titled "A Climatology of Tropospheric CO over the Central and Southeastern United States and the Southwestern Pacific Ocean Derived from Space, Air, and Ground-based Infrared Interferometer Data" (EOS NRA-97-MTPE-07). The total expenditure under this subcontract was $20,000 with an end date of March 11, 2002.

Under this sub-contract, the UW-SSEC has provided UMBC a copy of archive data of high spectral resolution infrared observations from two instruments developed and operated by the University of Wisconsin-Madison. The High-resolution Interferometer Sounder (HIS) instrument measures upwelling infrared radiances from the NASA ER-2 aircraft. The Atmospheric Emitted Radiance Interferometer (AERI) instrument measures downwelling infrared radiances from the surface.

AERI Datasets

AERI datasets provided to UMBC under this contract as summarized in Table 1. A brief description of each experiment is also provided.

Field Experiment	Date/Location	Data
CAMEX-I	September - October 1993/ Wallops Island, VA	AERI radiances
CAMEX-II	August 24 - September 15, 1995/ Wallops Island, VA	AERI retrievals/radiances, radiosonde, surface data
CAMEX-III	August 5 - September 20, 1998, Andros Island, Bahamas	AERI retrievals/radiances, GOES, surface, radiosonde data
SGP ARM	December 1999 – current / Oklahoma/Kansas	University of Wisconsin - Madison SSEC/CIMSS near real-time AERI retrievals/radiances for all SGP ARM systems
SGP ARM IOP (WVIOP 96, 97, 2000 and AFWEX)	August, September 1996, 1997, 2000 / DOE ARM SGP Lamont, Oklahoma	Redundant AERI radiances from SGP ARM IOP's where the UW-Winnebago operated the AERI-00 simultaneously with the SGP central facility AERI

Table 1. AERI CO Climatology Field Experiment Data Sets

The Convection and Moisture Experiment (CAMEX) conducted a series of field experiments beginning in 1993 (http://ghrc.msfc.nasa.gov/camex3/). The AERI participated in these experiments as part of a complement of ground based instrumentation. AERI retrievals provided near continuous monitoring of the temperature and water vapor in the planetary boundary layer as shown in Figure 1.

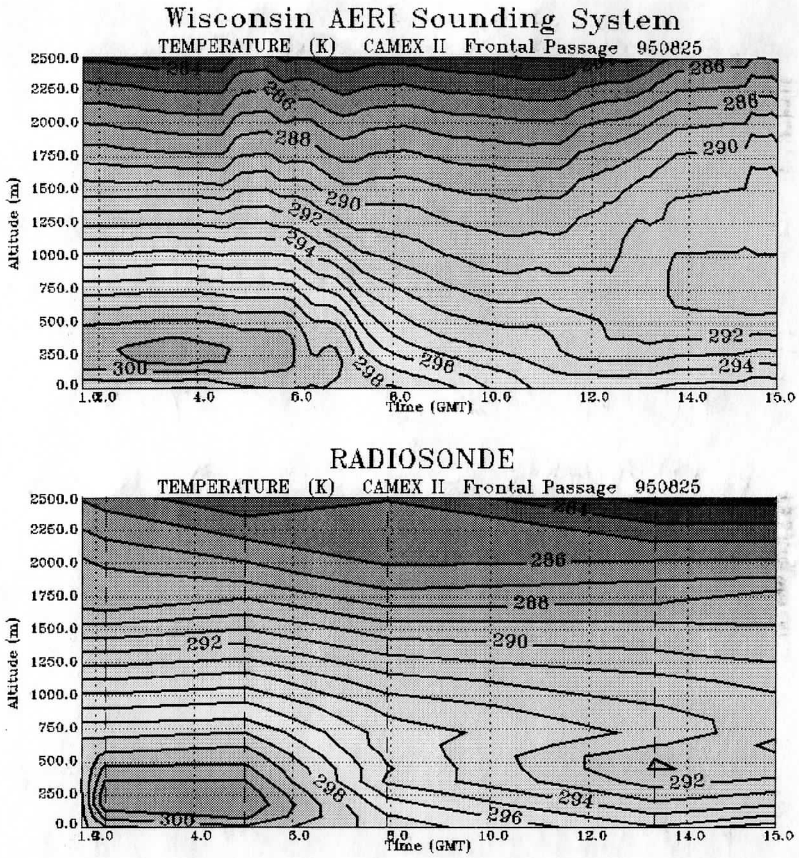


Figure 1. Time cross-section of AERI retrieved air temperature during a frontal passage on 25 August 1995 during CAMEX-II.

The AERI data from the Department of Energy Southern Great Plains Atmospheric Radiation Measurement (SGP ARM) site has been provided to UMBC for use in ground based carbon monoxide retrieval. Real-time data has been provided on a continuous basis along with data collected during intensive operating periods (IOPs). An intercomparison of two AERI systems is provided in Figure 2 from the 1997 Water Vapor IOP.

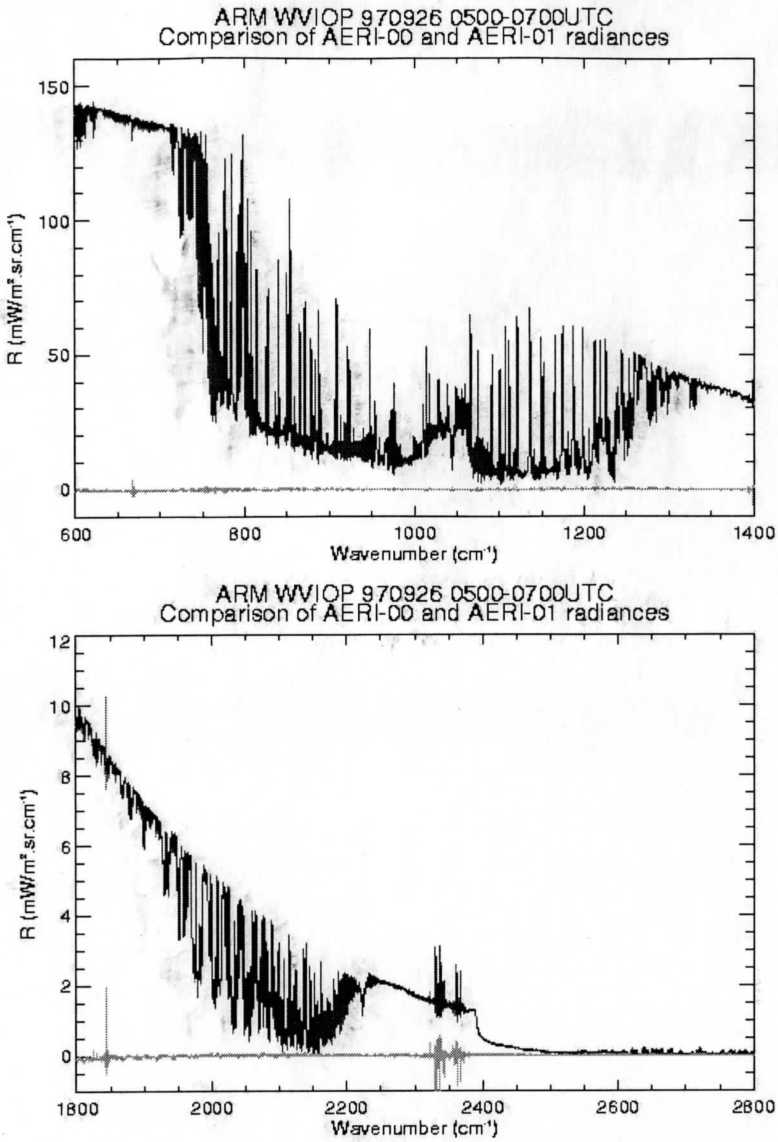


Figure 2. Overlap and difference plots of downwelling radiances observed by the two coincident AERI systems at the DOE ARM SGP site on 26 September 1997 showing excellent calibration reproducibility.

HIS Datasets

The HIS datasets provided to UMBC under this subcontract are listed below

- ASHOE (Airborne Southern Hemisphere Ozone Experiment) 1994
- SUCCESS (Subsonic Aircraft Contrail and Cloud Effects Special Study)
- CAMEX (I-II) (Convection and Moisture Experiment)

The ASHOE (Airborne Southern Hemisphere Ozone Experiment) campaign in 1994 included flights of the UW High-resolution Interferometer Sounder (HIS) instrument aboard the NASA ER-2 aircraft. The campaign was based in Christchurch, New Zealand with flights south toward the Antarctic vortex. Flight dates of the HIS instrument during ASHOE are given in Table 2.

Date (day)	Flight Times	Flight Target/Investigation
02 February 1994 (033)	21:08 -- 22:54	Test flight at NASA/Ames
04 February 1994 (035)	16:11 -- 00:04	Alaska flight
19 February 1994 (050)	17:11 -- 18:39	Test flight over Moffit AFB
13 April 1994 (103)	19:41 -- 03:22	South flight over ocean
15 April 1994 (105)	01:10 -- 03:36	Test flight / over volcano
05 June 1994 (156)	20:08 -- 21:08	Antarctic vortex
08 August 1994 (220)	22:11 -- 06:11	South flight over ocean
10 August 1994 (222)	21:12 -- 04:28	South flight over ocean
03 October 1994 (276)	21:42 -- 05:32	South flight over ocean
05 October 1994 (278)	21:17 -- 04:42	Southeast flight over ocean

Table 2. Flights of the HIS during the ASHOE campaign.

These data sets have been delivered via CD-ROM to UMBC for analysis towards developing a CO climatology. In addition to the radiance datasets, HIS temperature and water vapor retrievals were reanalyzed for this CO climatology research. Graphic plots of the HIS retrievals are presented as Figures 3-7. The plots include both the outward bound and the return leg and thus appear to be symmetric about the middle of the flight. The HIS retrievals which were originally produced at 0.5 degree latitude bins have been time interpolated to provide a profile for each radiance spectrum. This interpolated HIS retrievals have been provided as MATLAB "mat" files.

To support the use of the ASHOE data in climatological research, several variables have been extracted from the HIS radiance data. These include an estimate of CO optical depth from an online/offline technique developed at UW, the aircraft flight altitude, and brightness temperature time series in a window region (2400-2450 cm^{-1}) and an estimate of the mean atmospheric temperature (2200-2220 cm^{-1}). Figures 8-12 show the time series of these quantities for each of the flight days using the subarctic winter model atmosphere with a fixed surface temperature of 273K to compute an observed/calculated optical depth ratio. Note that most of the flights included a "dip" in altitude at the southern most extent of the flight in order to provide in situ sampling of the polar vortex.

A brief description of the online/offline CO effective optical depth technique is provided here for completeness. The form of the equation to be used can easily be derived from a single-layer atmosphere approximation

$$N_\nu^{Obs} = t_\nu \cdot N_\nu^{Surf} + N_\nu^{Atm} + t_\nu \cdot N_\nu^{Refl}$$

$$t_\nu = \exp[-\tau_\nu] \; and \; \tau = optical\ depth$$

$$Assume: N_\nu^{Refl} = 0; N_\nu^{Atm} = B_\nu(\overline{T_{Atm}})$$

where N^{Obs} is the S-HIS observed upwelling spectral radiance at an altitude of 20 km, t_ν is the atmospheric transmission for wavenumber ν, N^{Surf} is the emission from the surface, N^{Atm} is the atmospheric emission, N^{Refl} is the contribution from surface reflection, and B is the Planck emission function at a temperature T_A which approximates the mean atmospheric temperature. Neglecting the reflected radiance and substituting for the atmospheric emission leads to:

$$N_\nu^{Obs} \cong t_\nu \cdot N_\nu^{Surf} + B_\nu(\overline{T_{Atm}})$$

We then rearrange terms and split equation (2) into separate expressions for the on-line and off-line radiance.

$$t_{off} \cdot N_{off}^{Surf} = N_{off}^{Obs} - B_{off}(\overline{T_{Atm}})$$

$$t_{on} \cdot N_{on}^{Surf} = N_{on}^{Obs} - B_{on}(\overline{T_{Atm}})$$

We further assume that the surface emitted radiance is equal for both on-line and off-line spectral channels.

$$Assume: N_{on}^{Surf} = N_{off}^{Surf}$$

We may then divide equations (3) and (4) to obtain a ratio. We then use our earlier expression in equation (1) relating transmission to optical depth and substitute it,

Thus :

$$\frac{t_{on}}{t_{off}} = \frac{\exp(-\tau_{on})}{\exp(-\tau_{off})} = \frac{N_{on}^{Obs} - B_{on}(\overline{T_{Atm}})}{N_{off}^{Obs} - B_{off}(\overline{T_{Atm}})}$$

Take the natural log of both sides and the resulting expression becomes:

$$\Delta\tau = \tau_{on} - \tau_{off} = -\ln[\frac{N_{on}^{Obs} - B_{on}(\overline{T_{Atm}})}{N_{off}^{Obs} - B_{off}(\overline{T_{Atm}})}]$$

This result allows us to plot time series of changes in the optical depth of target gases. These results would be vulnerable to any dramatic change in the path distance between the emitter and the detector. The results therefore may be sensitive to conditions of heavy haze or cloud cover.

The selected wavenumbers are displayed in the table below.

Gas	On-line wn's	Off-line wn's
CO	2150.80	2151.77
	2154.667	2153.698
	2158.05	2159.02
	2158.52	2164.80
	2165.29	2166.75
	2165.77	2168.193
	2169.157	2170.126
	2172.54	2173.506
	2173.02	
CH4	1230.0	1230.96
	1240.62	1240.14
	1241.11	1241.59

Table 3. On-line/Off-line Wavenumbers

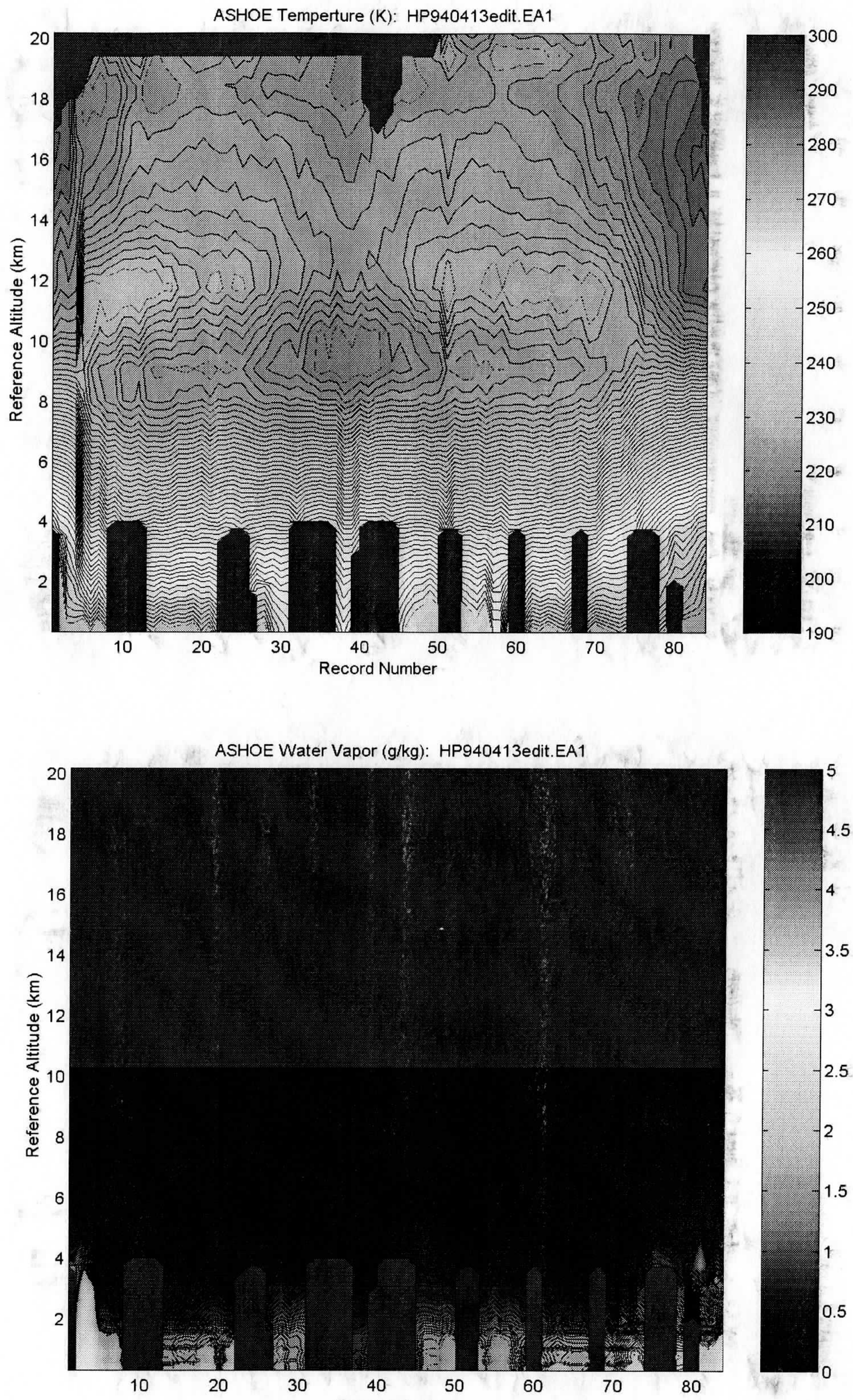


Figure 3. HIS retrieved temperature and water vapor cross-section for 13 April 1994.

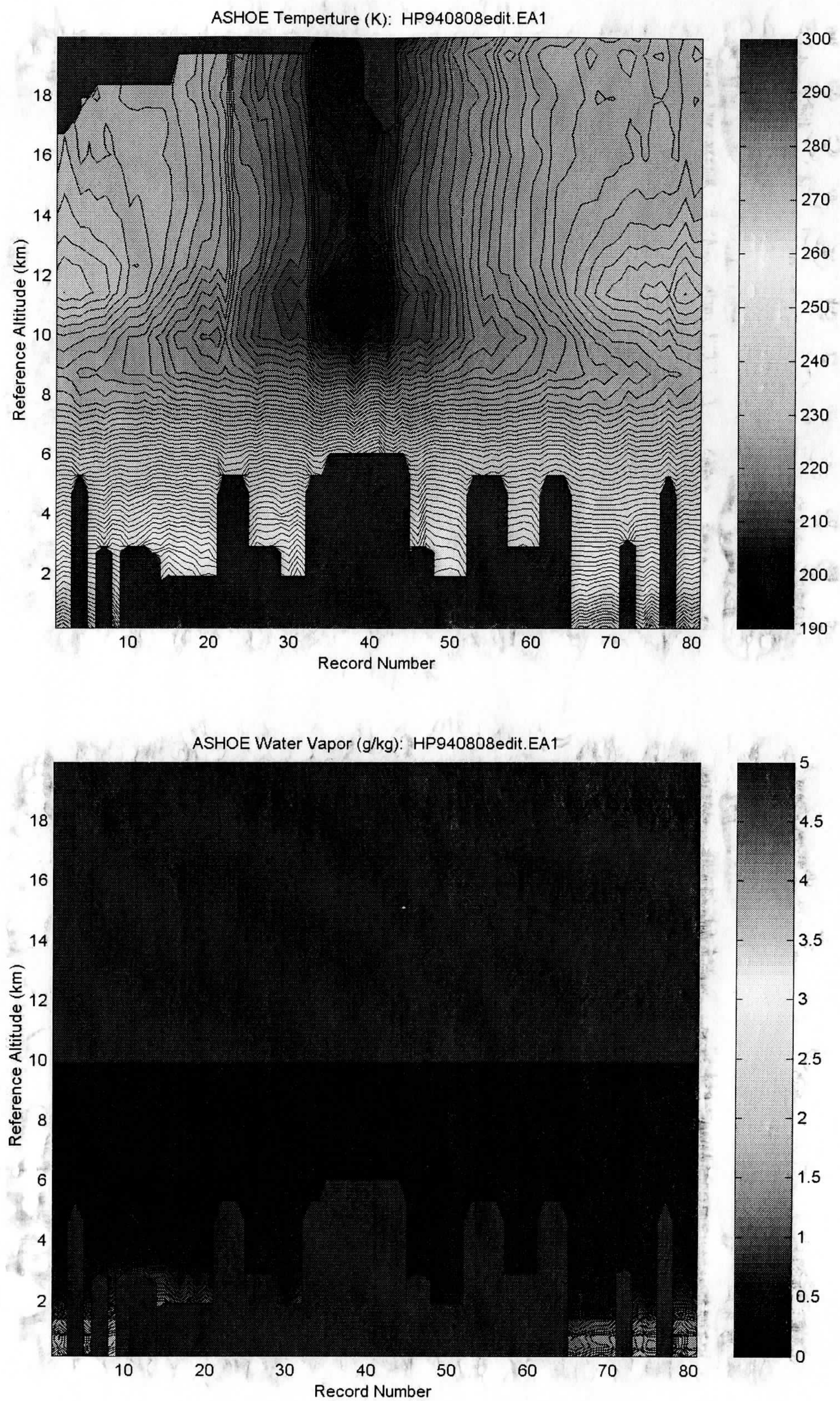


Figure 4. HIS retrieved temperature and water vapor cross-section for 08 August 1994.

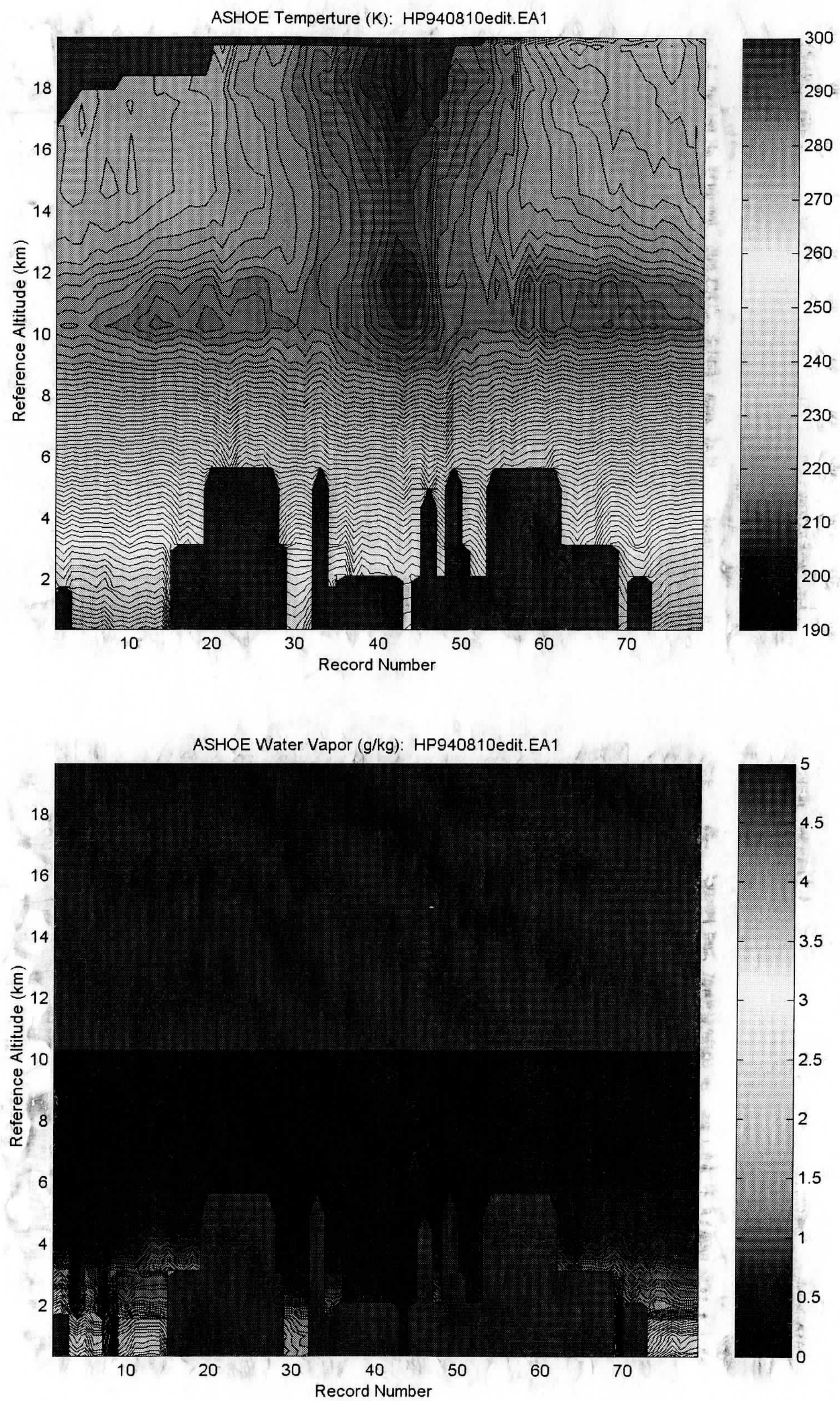


Figure 5. HIS retrieved temperature and water vapor cross-section for 10 August 1994.

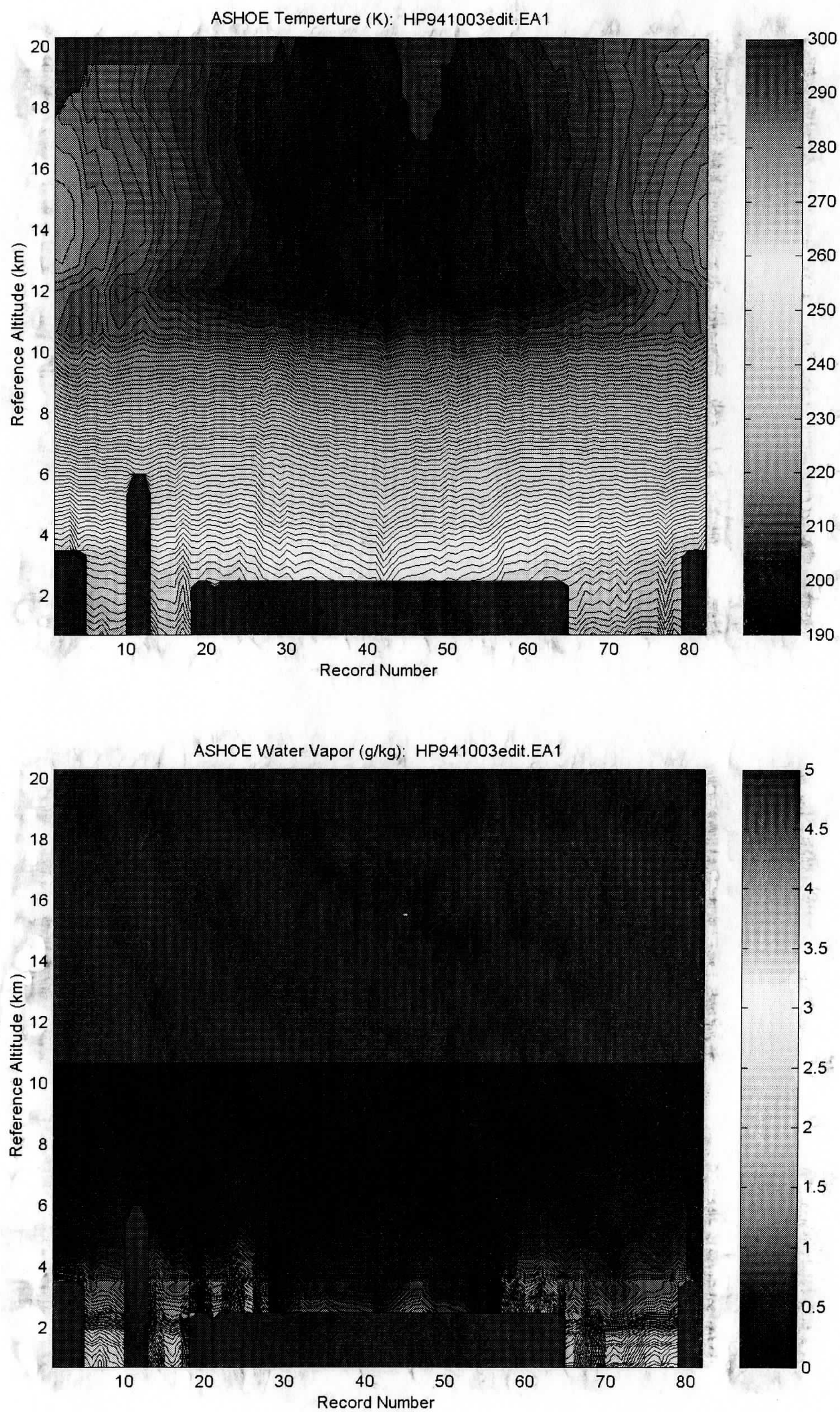


Figure 6. HIS retrieved temperature and water vapor cross-section for 03 October 1994.

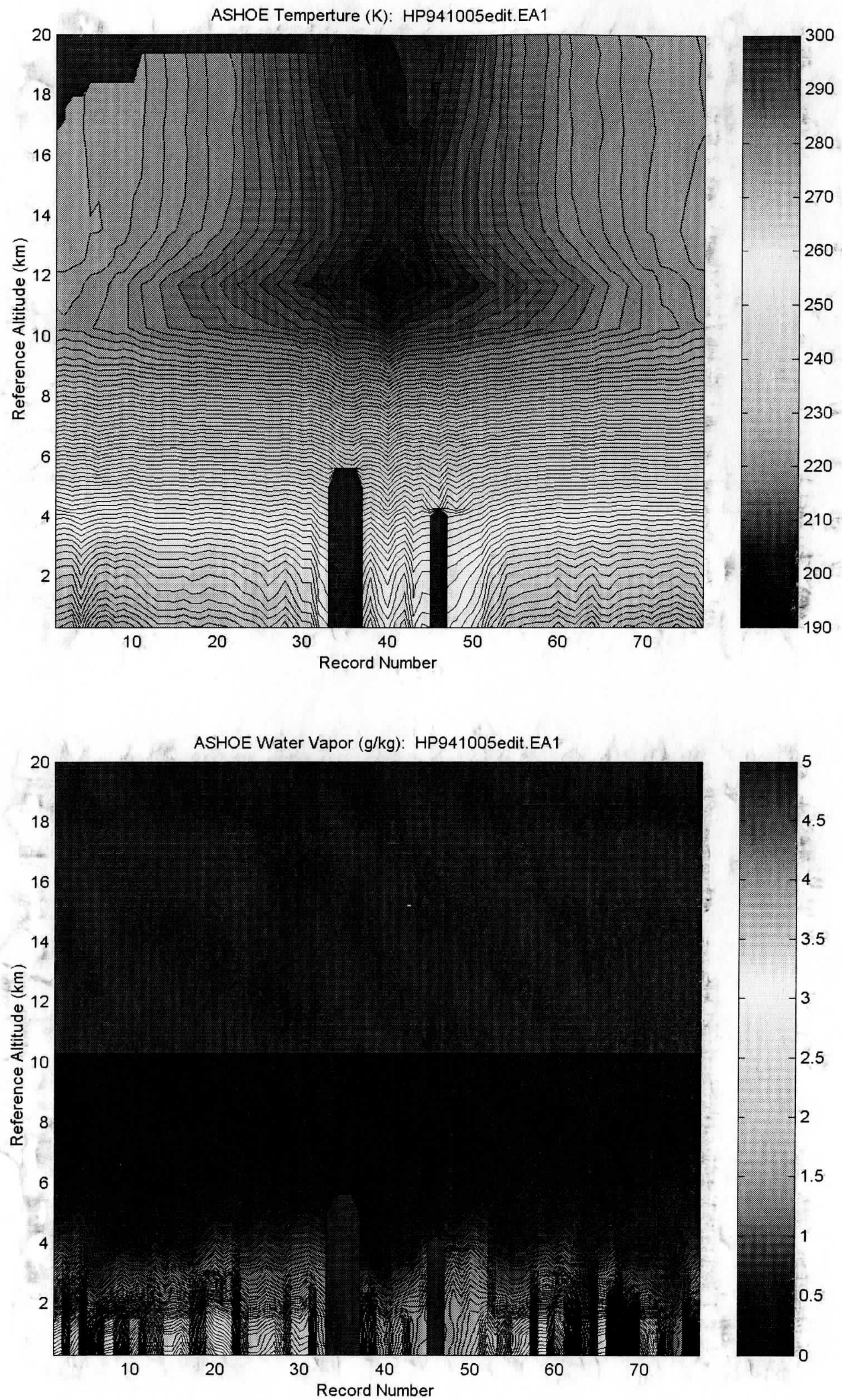
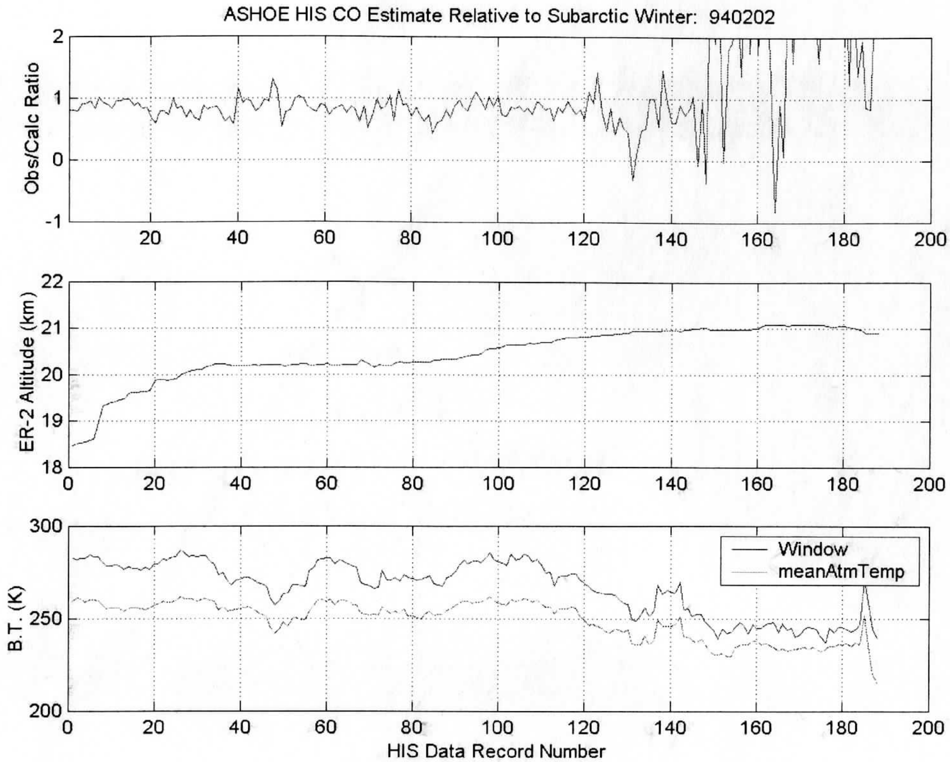


Figure 7. HIS retrieved temperature and water vapor cross-section for 08 August 1994.



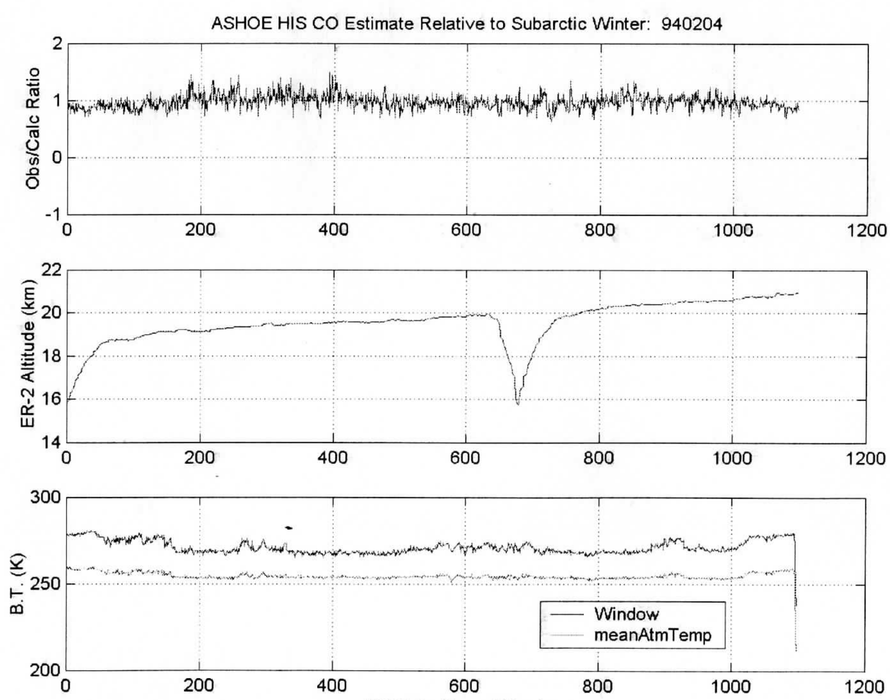
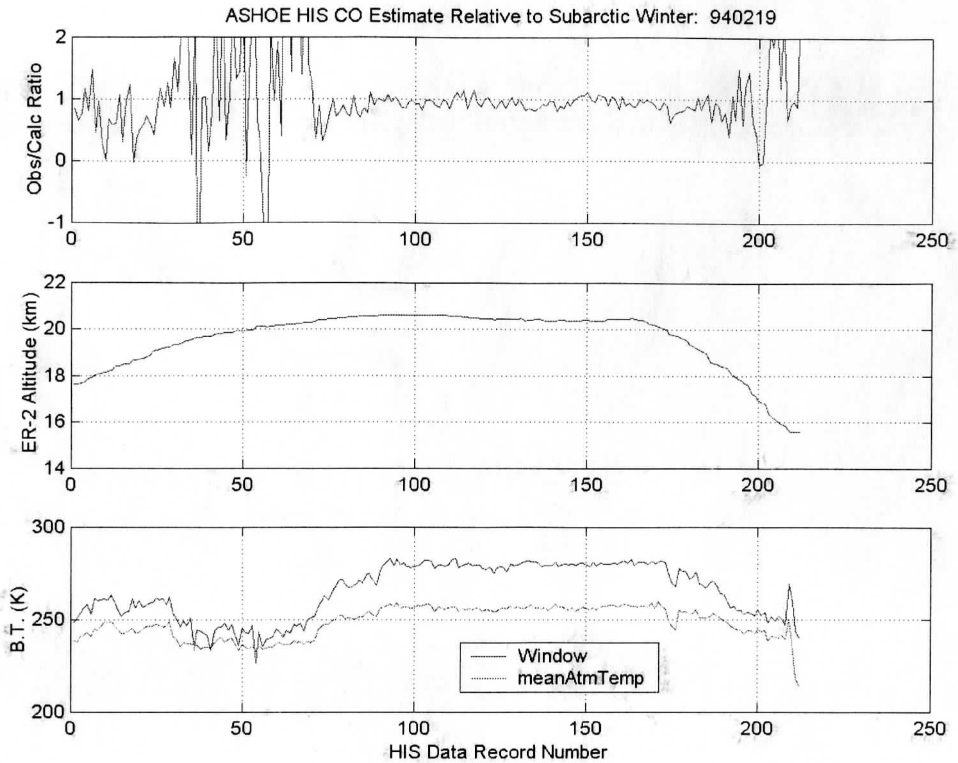


Figure 8. HIS observations from 04 Feb 1994.



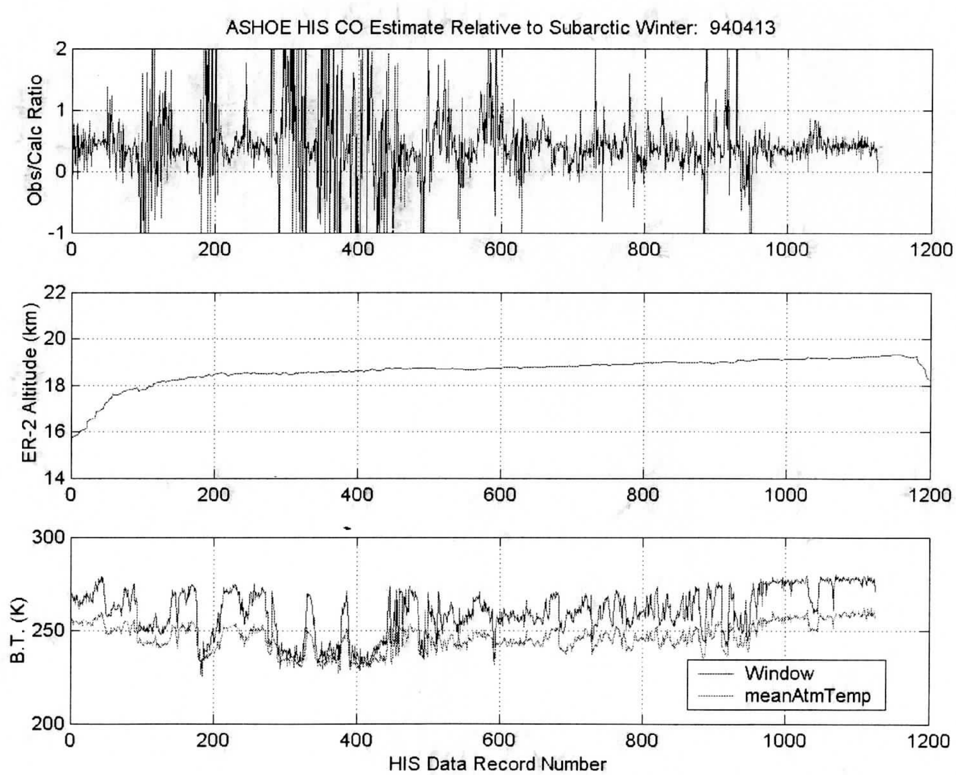


Figure 9. HIS observations from 13 Apr 1994.

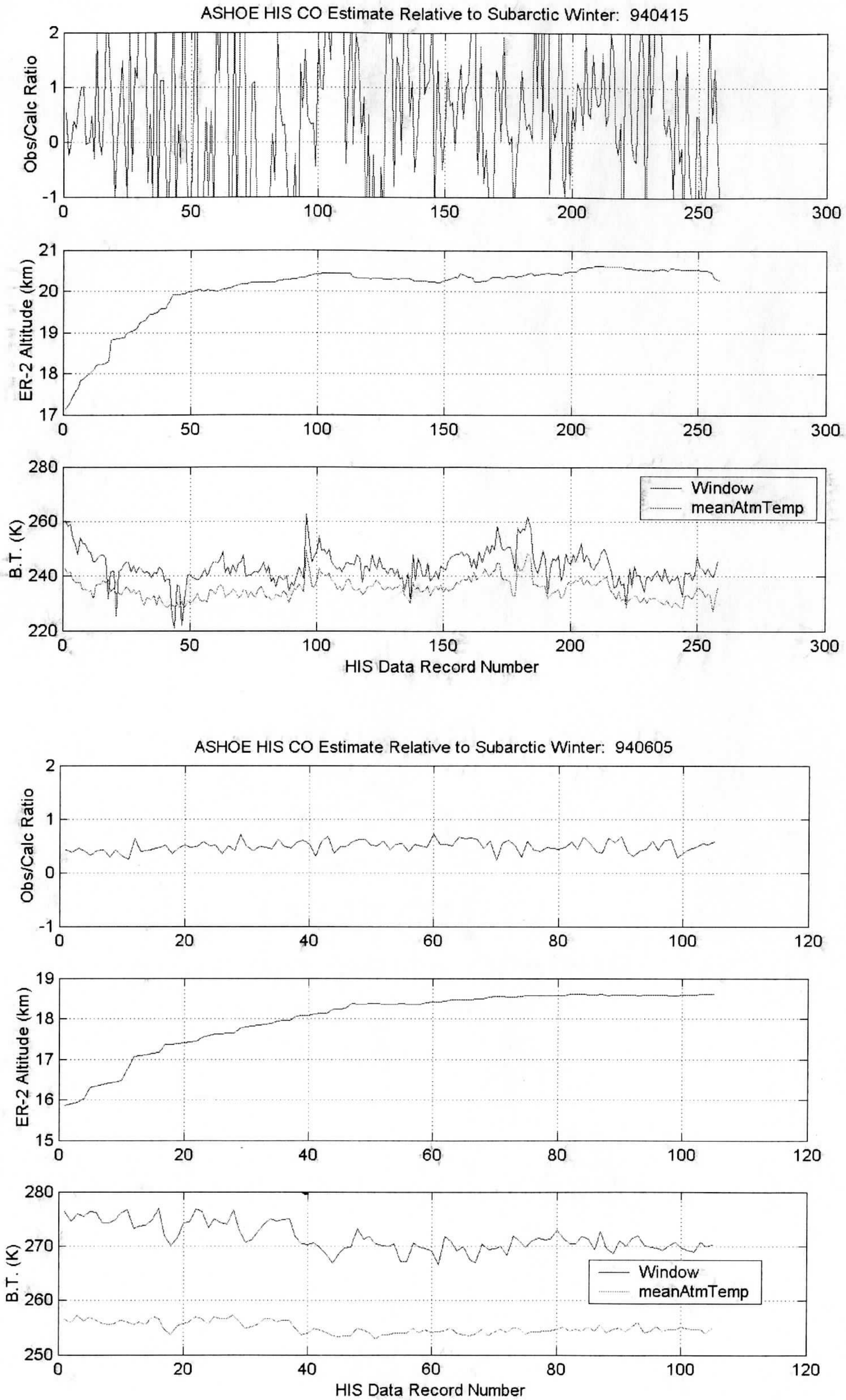
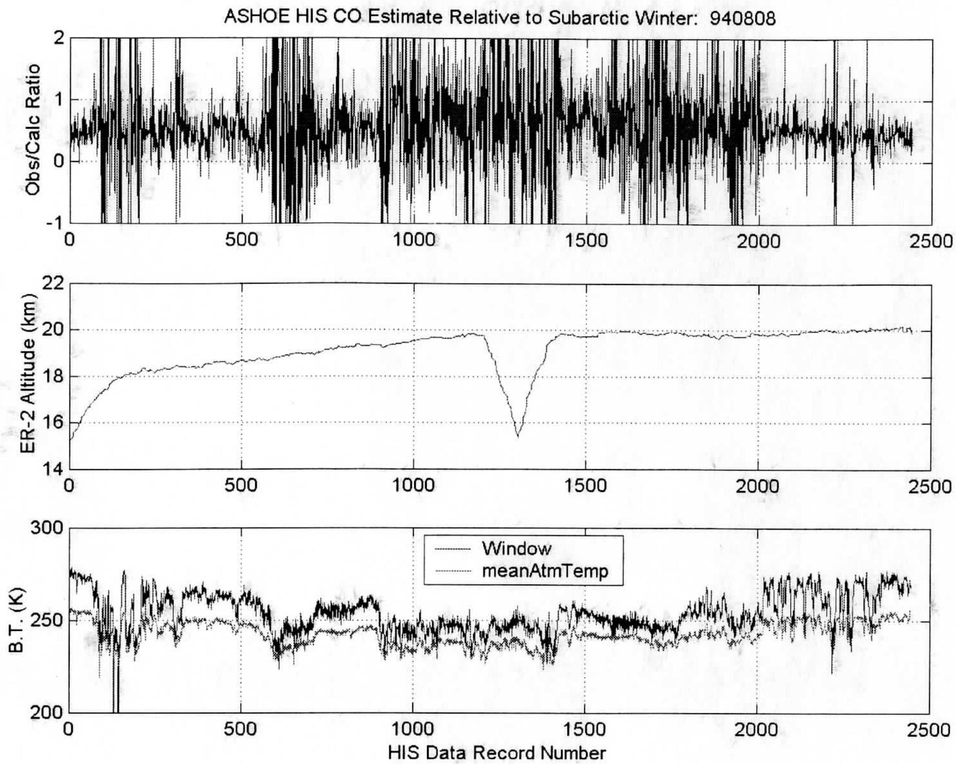


Figure 10. HIS observations from 05 June 1994.



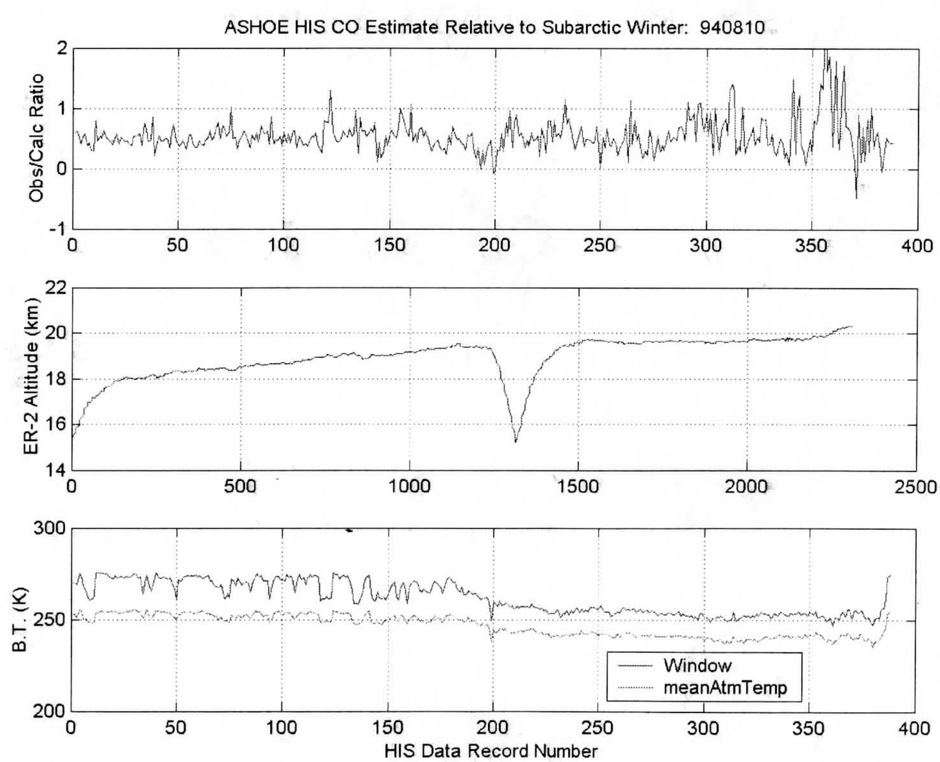


Figure 11. HIS observations from 10 Aug 1994.

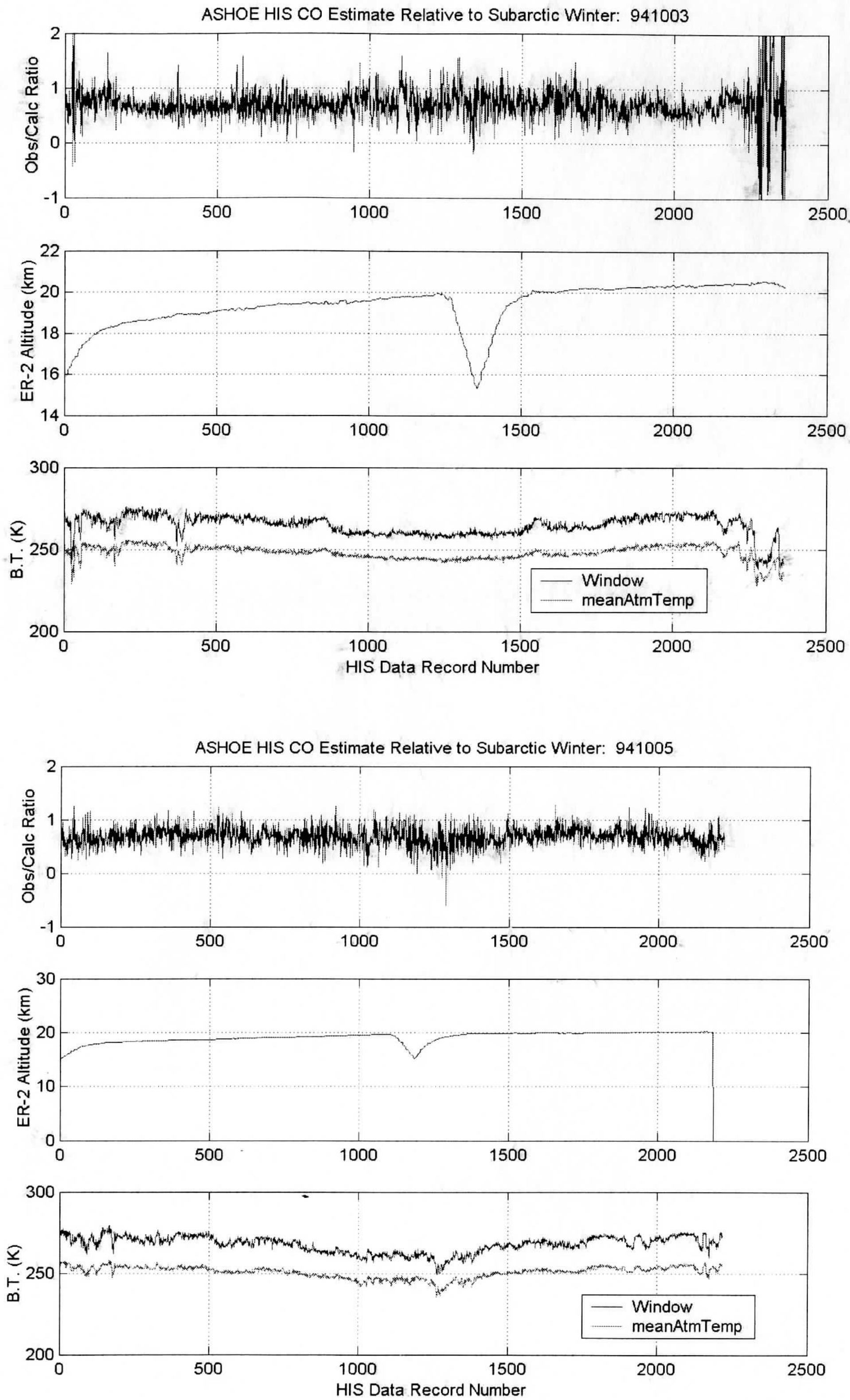


Figure 12. HIS observations from 05 Oct 1994.