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Retrieval Algorithms for the Halogen Occultation Experiment

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Contents

1 Introduction

This document describes the Halogen Occultation Experiment (HALOE) Level 2 processing software. It covers the details of the algorithms and the supportive data used to retrieve the various species now archived as part of the HALOE data set. It is hoped that it conveys the extraordinary care that went into designing and characterizing the instrument prior to launch, as well as the ongoing testing during its entire mission and how that information was used to the fullest extent. The intent is to document the algorithms used in Level 2 to serve as a basis for understanding the HALOE data products. Finally, it is hoped that this description will serve as a guide for future experiments to help insure that nothing is ignored or missed that might seriously impact the performance of those endeavors.

2 Overview of the Halogen Occultation Experiment

NASA's Mission to Planet Earth Program was an ambitious plan to provide observations of the earth's environment. These systematic and comprehensive observations were carried out by many types of instruments designed to measure the complex nature of Earth's physical and chemical processes. The Upper Atmosphere Research Satellite (UARS), launched into orbit in September 1991, was one of those observation platforms; it supported a host of instruments that globally measured and diagnosed the photochemistry, dynamics, and solar energy over much of Earth's atmosphere from the lower stratosphere and into the thermosphere.

One of the more complex instruments on UARS was the Halogen Occultation Experiment (HALOE); it performed flawlessly from launch until late 2005 when the UARS spacecraft was turned off due to battery failure. The HALOE mission supported the goals of UARS by providing long-term measurements of chlorine, nitrogen, and hydrogen-related compounds of the Earth's protective ozone layer. The purpose of these measurements was to provide data to assess the importance of anthropogenic versus natural sources of chlorine in the stratosphere. To obtain these data as accurately as possible with global coverage, a solar occultation technique was selected. To provide the required precision and sensitivity to measure these weakly absorbing species, gas filter correlation techniques were employed. Broadband radiometer measurements were performed for species with a stronger and more dominant spectral signature. Using both techniques, it was possible to measure temperature/pressure, O_3, H_2O, NO_2, NO, HCl, CH_4, HF, and aerosol extinctions to a high degree of accuracy over a large altitude range. Table 2-1 lists the HALOE channels, their spectral range, and the altitude ranges of their profiles. The spectral filter wavelengths are a function of the filter temperature, as will be discussed below; the values given in the table are for the approximate 5% points (i.e. points on filter edges that are 5% of maximum transmission) of the filters at near room temperature.

TARGET SPECIES	SPECTRAL RANGE	ALTITUDE RANGE
T/P	3529-3614cm-^{1}	30-85km
H_2O	1498-1523cm-^{1}	10-80km
NO_2	1582-1615cm-^{1}	10-55km
O_3	963-1067cm-^{1}	10-90km
NO	1876-1922cm-^{1}	10-150km
CH_4	2855-2916cm-^{1}	15-80km
HCl	2900-2982cm-^{1}	10-65km
HF	4031-4124cm-^{1}	10-65km
NO AEROSOL	1876-1922cm-^{1}	10-40km
CH_4 AEROSOL	2855-2916cm-^{1}	10-40km
HCl AEROSOL	2900-2982cm-^{1}	10-40km
HF AEROSOL	4031-4124cm-^{1}	10-40km

TABLE 2-1
HALOE channels showing target species, spectral location, and altitude range

The instrument measured NO, CH_4, HCl, and HF, using a gas-filter correlation technique in which these channels viewed the atmosphere through two optical paths; one path had a gas cell with the target gas and the second path (called the vacuum path or V signal) did not. The signals from these two paths were differenced in the instrument to provide a signal (called the DV signal) that was very sensitive to the target gas. Aerosol extinctions were retrieved using the V signals that accompanied the DV signals. HALOE also measured T/P O_3, NO_2, and H_2O using broadband radiometers.

3 Basic Principles

In order to meet and if possible exceed the goals of HALOE, every step from the design of the experiment, to building of the instrument, through comprehensive testing, to data analysis, and to the data validation approach had to be carefully thought through and planned. Every component in the measurement had to be precisely known, and any measurement artifact had to be removed or carefully characterized. During the data processing, any remaining instrument effects had to be removed or, if this was not possible, included in the corresponding simulated signals.

The fact that HALOE operated for so long without significant degradation is a major achievement of the engineers and scientists that designed, built, calibrated and operated the HALOE instrument. See Russell et al. [1993] for a detailed description of HALOE and see Reber et al. [1993] for a description of UARS. A description of each of HALOE’s retrieved species is contained in the special issue on the “Evaluation of the UARS Data” (J. Geophys. Res., 101, 10,163-10,174, 1996).

4 Level 2 Data Flow

The level 2 processing software consists of two steps, HALORET and CNDNS2D; HALORET uses the HALOE level 1 data files containing the HALOE measurements and performs the HALOE retrievals and CNDNS2D takes the output from HALORET and the Level 1 files and creates the Level 2 data product. The level 2 processing step requires only one file, but which changes with each day's processing – the level 1 file. All other input files do not change (e.g., the HITRAN spectral line files [Rothman et al., 2005]).

Four basic types or sources of information are needed in the Level 2 retrieval code. The first source is a user interface that runs the code. The second source is the data from pre-launch calibration and testing, and consists of parameters such as the field-of-view (FOV) functions. The third source is the level 1 data file that contains the HALOE signals, boresight positions, etc. Finally, additional data are read, such as data required for the diurnal gradient model or mixing ratio profiles of minor interfering species not measured by HALOE but needed in the transmission models for minor corrections. The flowchart in Figure 4-1 illustrates the Level 2 data flow.

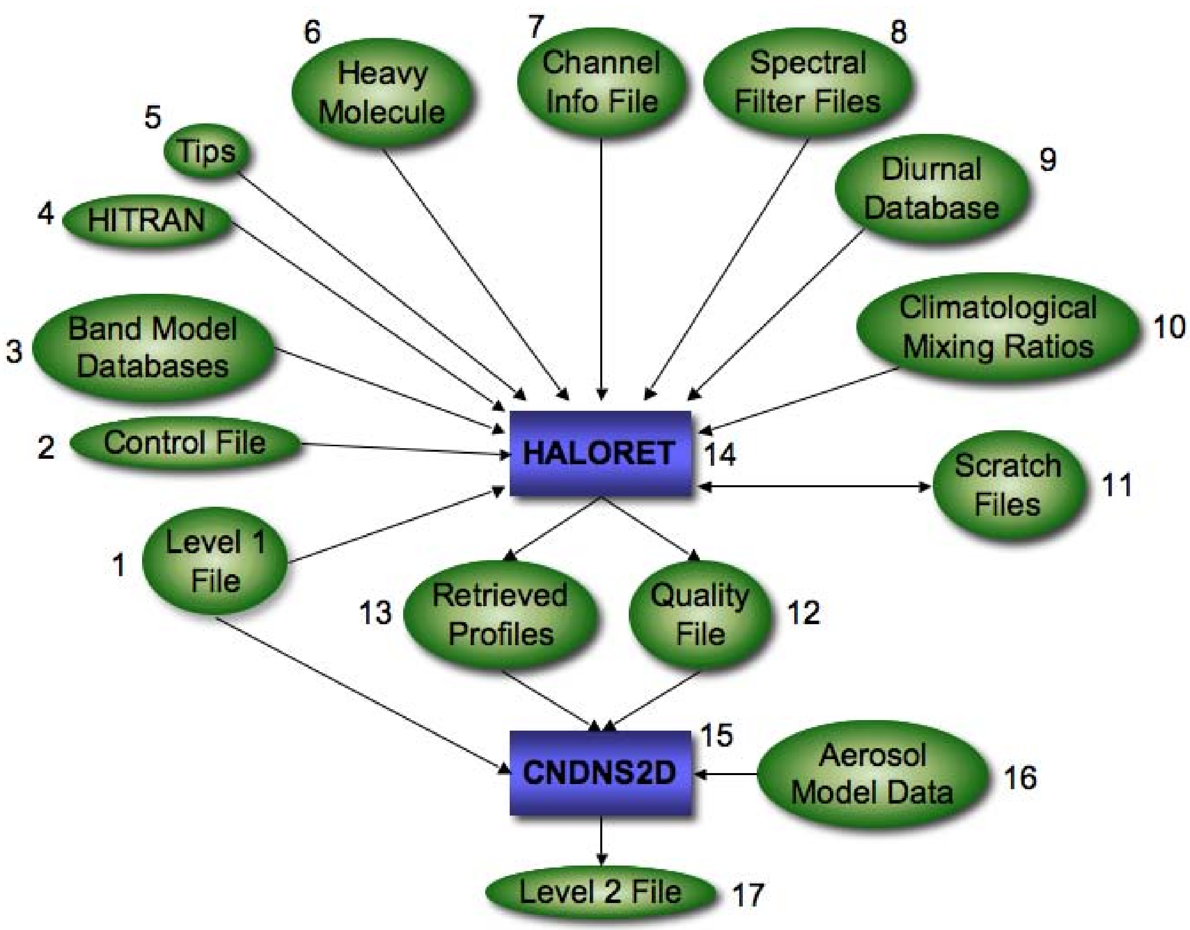

Figure 4-1
Level 2 Data Flow

A detailed list of all input and output files is contained in Appendix 4. Briefly, the files and software are

1. Level 1 file. A tremendous amount of planning went into the contents of the level 1 data files. The first step in the planning was to determine what information had to be retained from the data stream from the spacecraft. This information determined the format of the level 1 file. That file contains such things as, signals, Doppler velocities, boresight positions, mode (sunset/ sunrise), apparent zenith angles, latitudes, longitudes, earth radius, filter and gas cell temperatures, level 1 processing functions, and solar limb darkening curves. Appendix 1 contains the Level 1 file format.
2. The control file. This file is how the user interfaces with the retrieval software.
3. Band Model databases. These tables are for the band model transmission calculations used in simulating the radiometer channels.
4. HITRAN. This file contains the spectral line parameters needed in the gas correlation channel, line-by-line transmission model. See Rothman et al. [2005] for information on HITRAN.
5. TIPS. Total Internal Partition Sums file needed by the line-by-line model [Gamache et al., 1990].
6. Heavy Molecule. Data needed by the line-by-line code to model the absorption of large molecules. This data came from a HITRAN release, but it was never used in processing as the absorptions due to large molecules never needed to be included.
7. Channel information file. A file containing parameters needed to run the line-by-line code. It contains gas cell conditions and various channel dependent parameters.
8. Spectral Filter files. The measured HALOE spectral filters that are needed in the line-by-line model.
9. Diurnal database. Tables used for the diurnal gradient model.
10. Climatological mixing ratio input file. Mixing ratio profiles that are used as first guesses or as interferents; there are two sets of profiles – one for the northern hemisphere and one for the southern hemisphere. The profiles are pulled from the file with each event processed.
11. Scratch files. These files are produced in the retrieval process and are used by the software as a workspace.
12. Quality Control. This file contains the precision estimates of the retrievals and other information pertinent to the quality of the retrievals.
13. Retrieved mixing ratios and aerosol extinctions. The results of the Level 2 retrievals.
14. HALORET. The actual retrieval code.
15. CNDNS2D. Software that reads the retrieval results, quality files, and the level 1 file to produce the level 2 file.
16. Aerosol model data. Information used by CNDNS2D to calculate additional aerosol parameters for inclusion in the Level 2 file. These are aerosol density, median radius, distribution width, concentration, surface area, volume, and effective radius.
17. Level 2 file. The level 2 final product containing the retrieved profiles and the level 1 data needed to rerun the retrievals if needed. Appendix 2 contains a description of the Level 2 file contents.

The level 2 processing step was composed of a suite of software written and maintained by the HALOE software team. While most of the HALOE code was written in FORTRAN, a software development tool created by GATS, Inc., known as S^3, was used in the main drivers and maintained simplicity by allowing modification of the software without high level code changes; it forced modularity even when complex modules were involved. The software ending with the suffix (.pct or .pdt) or beginning with S^3 were part of this system. The S^3 routines were converted to FORTRAN using a conversion algorithm for use on the CDHF cluster of computers that did not support S^3.

5 Level 2 Algorithm Overview

An outline of the Level 2 software is shown in figures 5-1 to 5-9; pcts are shown as rectangles, S^3 logic as hexagons, and FORTRAN modules are shown as ovals.

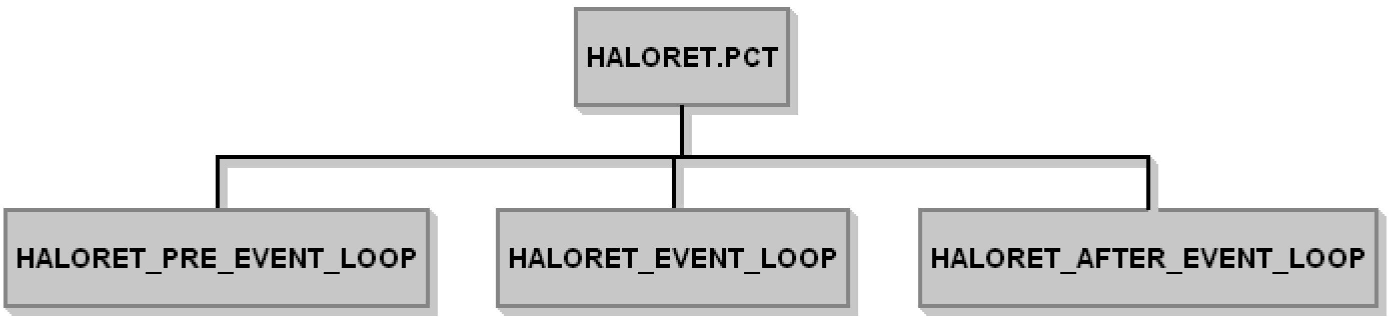

Figure 5-1

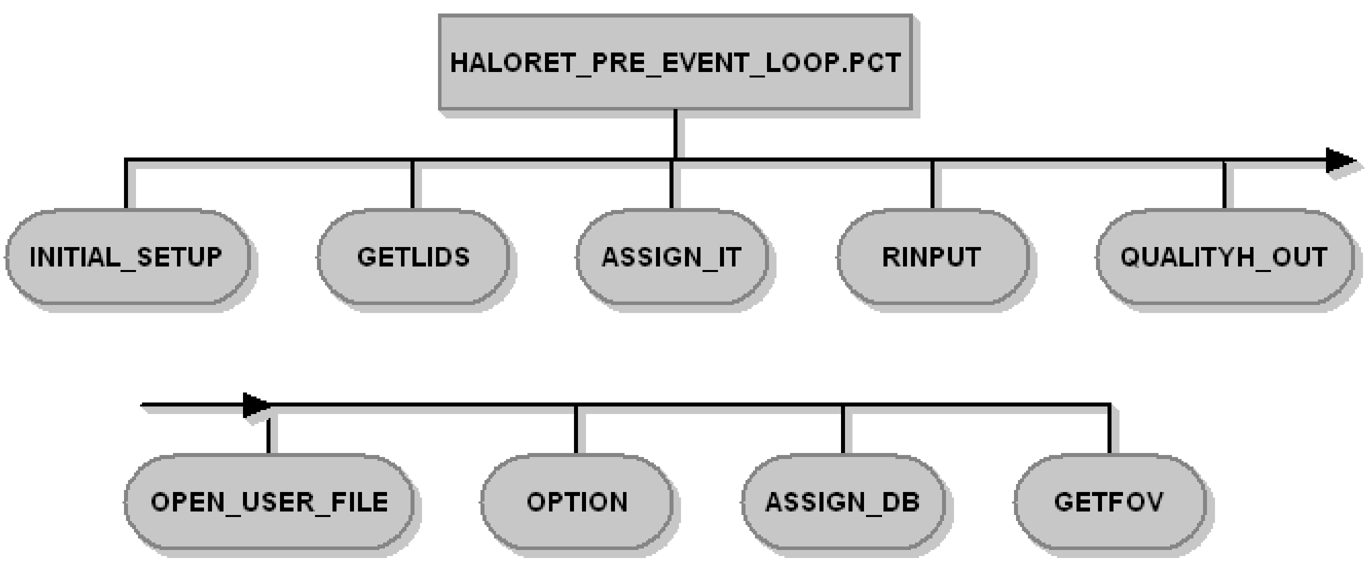

Figure 5-2

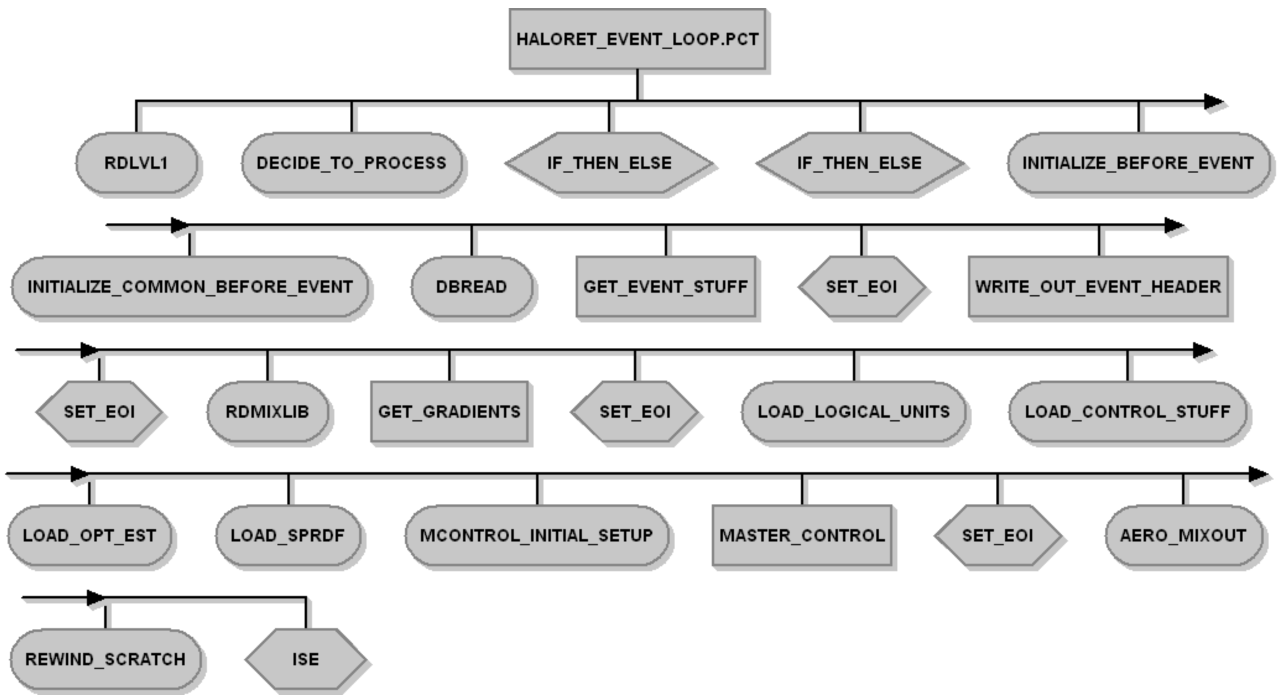

Figure 5-3

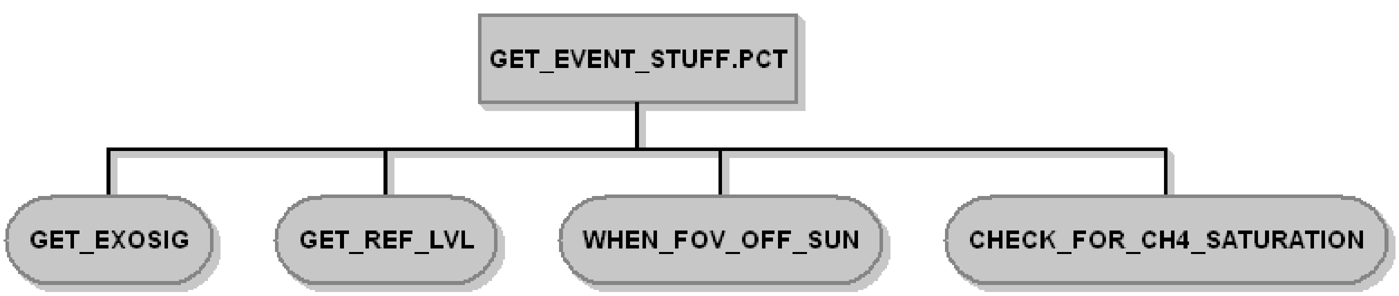

Figure 5-4

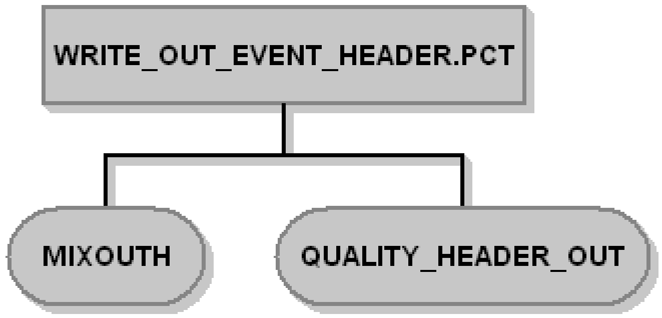

Figure 5-5

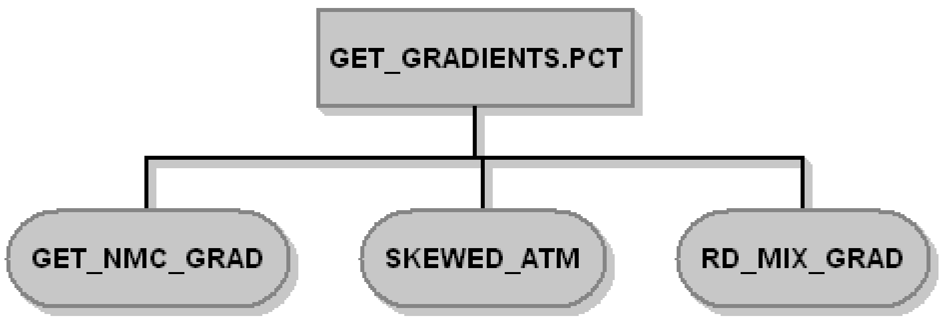

Figure 5-6

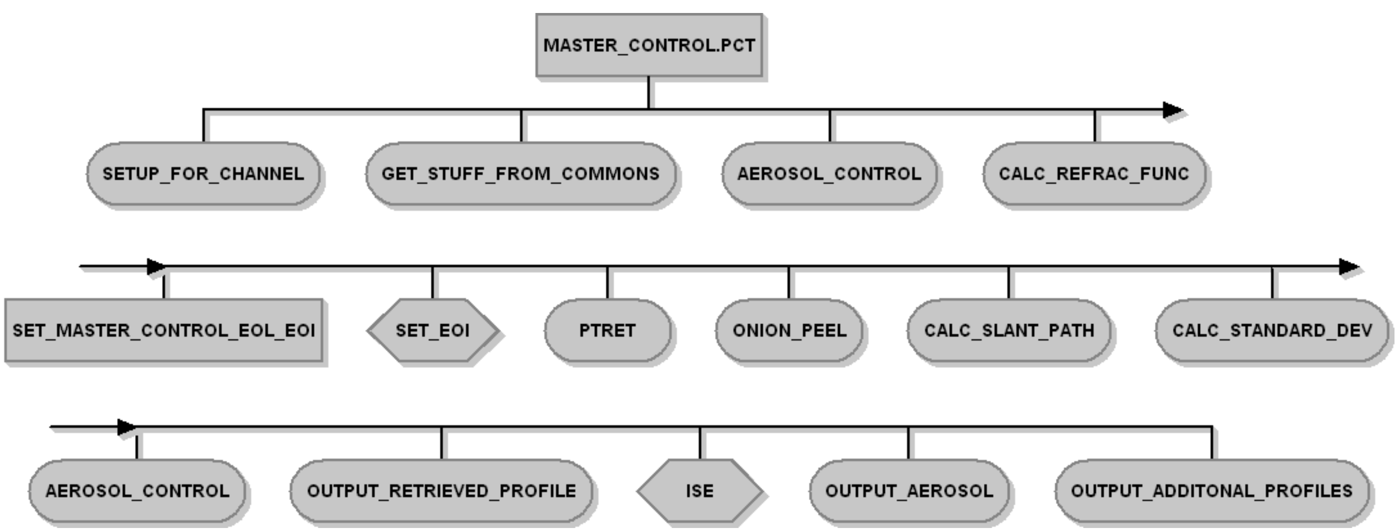

Figure 5-7

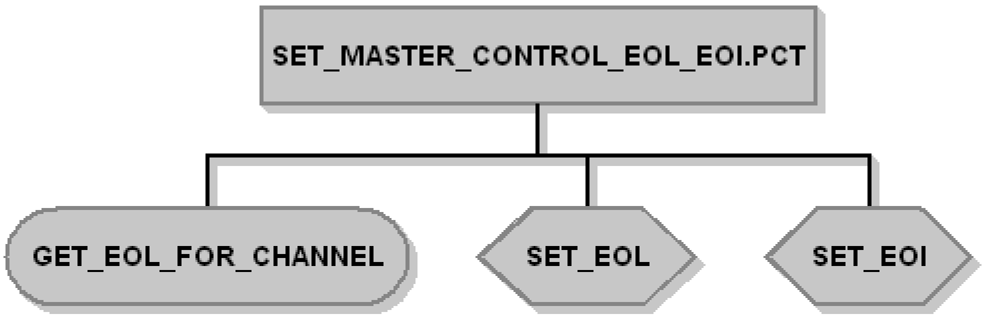

Figure 5-8

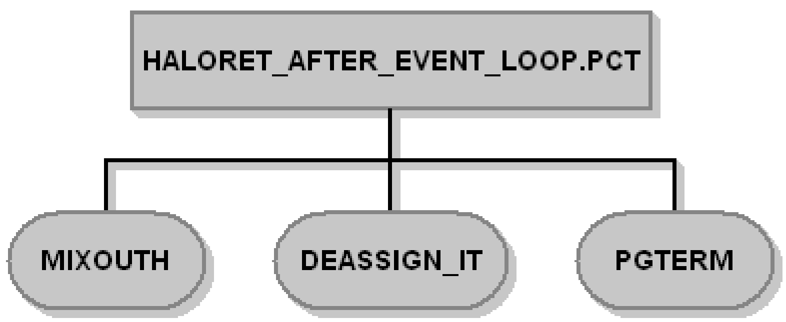

Figure 5-9

The highest level routine, HALORET.PCT, calls three steps in processing; it sets things up for processing by doing initialization; the retrievals are then done in an event processing pct where the routine PTRET does the P/T retrieval and ONION_PEEL does the species retrievals; finally, post event issues are performed. Many of the routines shown will be discussed in the algorithm descriptions that follow.

While the inversion code can do the retrievals in any order, the retrieval of the HALOE species is done in a specific order to guarantee that the retrievals are self-sufficient, i.e. not dependent on climatological values for any interferent species. This fact has tremendous advantages for validating the HALOE retrievals. The only climatology used in Level 2 is for N_2O that is a minor interferent in several channels.

To achieve this goal, the typical channel order for V19 is shown in Table 6-1.

Species	**Channel index**	**Channel**	**Interfering Species**
T/P	1	CO_2	CO_2, H_2O, N_2O, aerosols
NO	5	NO DV	H_2O, CO_2, N_2O, aerosols
NO aerosol	12	NO V	NO, H_2O, CO_2, N_2O, O_3
O_3	4	O_3	N_2O, CO_2, H_2O, aerosols
NO aerosol	12	NO V	NO, H_2O, CO_2, N_2O, O_3
H_2O	2	H_2O	CH_4, O_2 continuum, aerosols
T/P	1	CO_2	CO_2, H_2O, N_2O, aerosols
NO	5	NO DV	H_2O, CO_2, N_2O, aerosols
NO aerosol	12	NO V	NO, H_2O, CO_2, N_2O, O_3
H_2O	2	H_2O	CH_4, O_2 continuum, aerosols
NO_2	3	NO_2	CH_4, H_2O, O_2 continuum, aerosol
O_3	4	O_3	N_2O, CO_2, H_2O, aerosols
CH_4	8	CH_4 DV	H_2O, NO_2, HCl, aerosols
NO_2	3	NO_2	CH_4, H_2O, O_2 continuum, aerosol
HCl	9	HCl DV	H_2O, NO_2, CH_4, O_3, aerosols
HF	10	HF DV	H_2O, O_3, CH_4, aerosols
CH_4 aerosol	13	CH_4 V	H_2O, NO_2, HCL, CH_4
HCl aerosol	14	HCl V	H_2O, O_3, CH_4, HCl
HF aerosol	15	HF V	H_2O, CO_2, CH_4

TABLE 6-1
V19 channel order

The first retrieval step is the initial temperature/pressure retrieval. This first temperature retrieval uses climatological H_2O and has no aerosols included, but does give a first cut at a T/P profile. One important note is that the CO_2 mixing ratio profile that is used comes from a time dependent model that increases with time and comes from the NOAA GMCC program obtained from Rosenlof [1995]; the model has a further altitude dependence to account for a 4 year lag of CO_2 in the stratosphere compared to the lower troposphere for the GMCC data. Next, a retrieval of NO is performed with all interfering species based on climatology; this first guess NO profile is used as an interfering species in the NO channel aerosol retrieval that follows. The NO aerosol retrieval is done to permit the calculation, using a wavelength dependent model, of an aerosol extinction profile needed in the O_3 retrieval. Note that O_3 is an interfering species in the NO V channel aerosol retrieval that is updated after this O_3 retrieval. At this point, a retrieval of H_2O is performed because a good estimate of an aerosol profile is available now. Next, the T/P retrieval is repeated and refined because both the aerosol extinction profile and a H_2O profile are available for inclusion in its algorithm.

Following the refinement of the T/P retrieval, the NO retrieval is done one last time using the retrieved species instead of the climatological profile that was used in its first retrieval. A final NO aerosol retrieval is also performed. The results are used to estimate aerosol interfering extinction [Hervig et al., 1995] for the H_2O, NO_2, and O_3 retrievals that follow. With those species retrievals completed, the CH_4 DV retrieval is executed followed by a second NO_2 retrieval that makes use of the CH_4 product. The last two gas species, HCl and HF, are retrieved next, followed by the CH_4, HCl and HF aerosol retrievals from the gas correlation channel V signals. One last point: as previously mentioned, some of the derived aerosol products of the Level 2 files are actually calculated in the routine CNDNS2D that is run after the HALORET retrieval code.

6 Components of Simulated Signals

The retrievals of the HALOE species (mixing ratios, temperatures/pressures, and aerosol extinctions) were fundamentally derived by comparing HALOE signals and simulated signals. To calculate simulated signals, the following need to be addressed:

Geometry
Transmission calculations

a. transmission models
b. Spectral line parameters
c. Spectral filters
d. Gas cell characteristics
e. Aerosol model
f. Diurnal model

Field of view (FOV)
Solar limb darkening curve (SLDC), i.e. solar source function
Refraction model
Gaussian smoothing function
Signal formulation

Quickly, giving an overview of these topics, the geometry step includes setting up the onion-peel geometry based on the user input tangent layers; this step though obviously rather complex, is handled via a minimal interface with the BANDPAK libraries [Marshall et al., 1994]. The transmission calculation uses either a band model or a line-by-line calculation depending on channel and, like the geometry call, is user friendly in that the call to the routines is not particularly complex. A very important aspect of simulating the signals is the bending of the ray paths through the atmosphere due to refraction; this is also handled by the libraries. Because HALOE was an occultation instrument, it used the solar disk as an intensity function and viewed the sun as it rose or set though the atmosphere; refraction causes the solar image to squash as a function of apparent altitude, and this must be modeled correctly to avoid introducing an error in inferred transmission. In simulating the signals, any processing artifacts that remain in the HALOE measurements need to be modeled; this step includes accounting for the Gaussian smoothing function that was applied to the signals following the removal of the electronic Butterworth filter. The field of view (FOV) functions measured prior to launch and needed in convolving the transmissions with the solar source function are stored in Data statements in the Level 2 code. Finally all these individual components are brought together during the simulated signal convolution. These components will next be reviewed in detail to give a comprehensive view of the steps taken to calculate a simulated signal.

7 Geometry

The geometry model that is used is part of the GATS BANKPAK/LINEPAK packages. These two sets of software routines perform atmospheric radiative transfer calculations as will be discussed in detail below. They are proprietary software developed by GATS and are used as an integral part of the HALOE Level 1 and Level 2 codes. These codes take the user supplied inputs such as the tangent layer scheme (apparent tangent altitudes), temperature and pressure profiles, and earth radius and construct an onion-peeling geometry as shown in figure 7-1. Note that in this simplified drawing the ray paths are shown as straight lines, but the software does account for refraction that substantially bends the ray paths. All of the information related to these geometrical calculations are handled internally by BANDPAK and LINEPAK [Gordley et al., 1994] that greatly simplifies the use of the model.

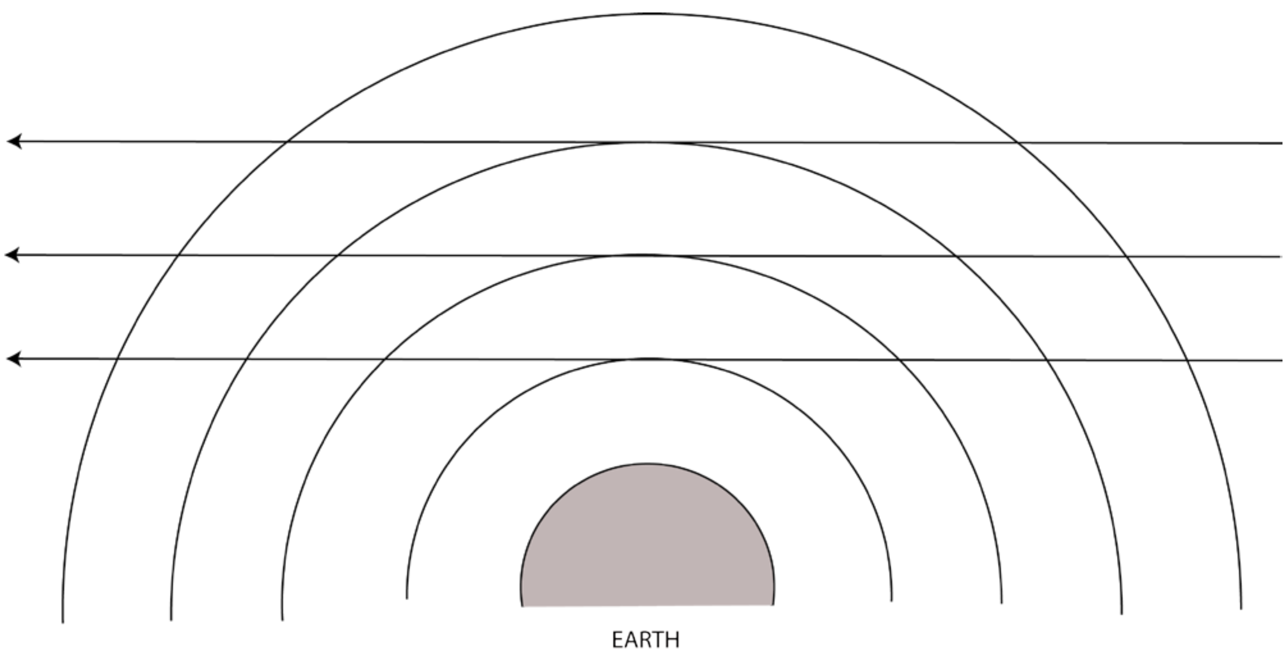

Figure 7-1
HALOE Onion Peel Geometry

This onion peel geometry employs an interleave approach. The term interleave refers to the iterative selection of subsets of the onion peel layer scheme. As shown in figure 7-2, the input HALOE signals (in the Level 1 file data) are on a 0.3-km spacing.

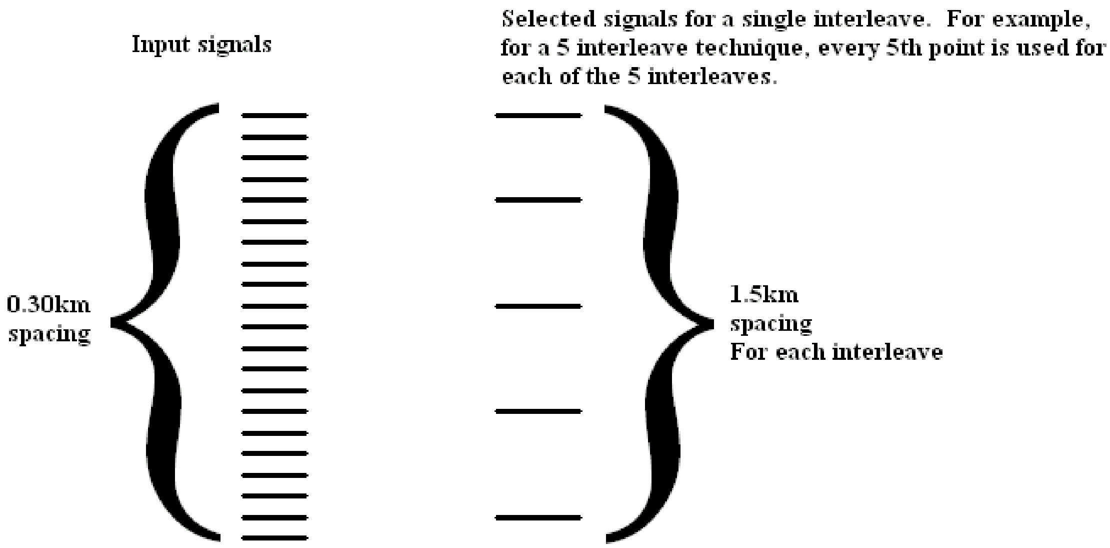

Figure 7-2
Interleave example

As an interleave example, if the full tangent layer scheme for the retrieval goes from 60km to 3.0km in 0.3km steps and a 5 interleave technique was to be implemented, every 5th layer is used to form an onion-peel layer scheme that has a spacing of approximately 1.5km. This onion layer geometry is used to calculate the transmissions using either of the two forward model options. The 1.5km spacing closely matches the HALOE measurement resolution, and increases stability of the retrieval and reduces overall computation demands by a factor of the interleave, in the above example, a factor of 5. Following the retrieval for a given tangent layer, another subset of tangent layers offset by one measurement point is extracted and is used for that retrieval. This scheme was repeated until the bottom retrieval point was reached. As will be discussed in Section 14, the convolution of the FOV over the simulated transmission profile could be done over either the full tangent layer scheme or a single interleave scheme; for V19 the convolution was performed over the full tangent layer scheme (in this case, 0.3km). In addition, as will be described in Section 15, the routine OPTIMAL_EST that calculates the estimates of mixing ratio/aerosol extinction during the retrieval process also uses the full layer scheme (for this example, 0.3km).

8 Transmission Calculations

8.1 Transmission Models

Perhaps the most important piece in the HALOE retrieval process is the forward model that accurately calculates the transmission. An error in the transmission model directly affects the accuracy of the retrievals. In the case of the gas correlation channels, extreme accuracy is required to avoid introducing errors. For HALOE, the issues that needed to be addressed in the forward model included, band model versus a line-by-line model, spectral filter characterization, gas cell characteristics, an aerosol model, and a diurnal species model. Two models are used to determine transmission. The first uses BANDPAK, i.e. band models, and is employed in the radiometer channel retrievals to obtain T/P, H_2O, NO_2, O_3 and aerosol extinction. The band model uses pre-calculated look up tables of absorption to very rapidly calculate atmospheric transmissions. Each species for a given channel has a set of absorption tables. In addition, there are overlap databases that are used to correct for the spectral overlap of different absorbers. These tables consist of absorptions for a set of temperatures, pressures and masspaths. Note that the absorptions are also weighted using the solar blackbody function for that channel.

Depending on channel and species, the band model uses either the Emissivity Growth Approximation (EGA) technique [Gordley and Russell, 1981], a continuum option, or an aerosol extinction option. The type of model needed is defined in the routine OPTION. In these band models, absorption tables are calculated using HITRAN prior to operational processing. Since the spectral integrations are performed in the creation of the databases and not during operational processing, the radiometer retrievals are very fast computationally. The HITRAN spectral lines are integrated over the spectral filter function for the channel (see section below). Absorption errors using the band models are on the order of 1% or less.

The gas correlation channels require a more exact transmission calculation than the radiometer channels. The software package LINEPAK is used for doing the required line-by-line calculation. LINEPAK uses HITRAN line parameters to calculate the spectra but does so with an extremely fast and accurate algorithm. The necessary resolution and other required information for performing the line-by-line calculations were predetermined during in-depth studies and are read in from a channel info-file. The resultant spectra are shifted to include Doppler velocity (spacecraft-atmosphere) induced shifts that vary from +/- $0.01 cm^{-1}$ to +/- $0.10 cm^{-1}$ depending on Doppler velocity and wavelength. Then the spectra are convolved over the temperature corrected filter function (see Section 8c) and the channel dependent solar blackbody function.

There is an important difference between the band model transmission output for the radiometer channels and the line-by-line model transmission output for the gas correlation channels. For the radiometer channels there is a single transmission for each tangent layer. For the gas correlation channels there are actually two transmissions (or two τs) per layer. As mentioned above, the gas correlation channel signals are differences between a gas path and a vacuum path in the instrument and to deal with this LINEPAK outputs a "wide" term and a "narrow" term. The "wide" term is easy to understand; it is the integration of the transmission under the spectral filter function just as in the case of the radiometers. The "narrow" term is more complicated. It is the integration under BOTH the spectral filter and the effective filter formed by the gas in the gas cell. The simulated transmission difference signal, DV, is then

(8-1) $$DV = \text{constant}^*(\tau(\text{wide}) - \tau(\text{narrow})),$$

where the constant is a function of HALOE optics, the narrow and wide transmissions, and the solar source function. The constant, referred to as GBAR minus one, is defined as an integral over the spectral band pass ν and assumes DV = 0 when looking above the atmosphere, as equation 8-1 implies. With that assumption:

$$(\overline{G}-1)=\frac{\int SF_N dv}{\int S(F_W-F_N)dv}, \tag{8-2}$$

where

S = solar spectral source function
F_N = effective narrow band
$= f\tau_c\left[\tau_2-\tau_g\tau_1\Big/\overline{(\tau_1/\tau_2)}\right]$
F_W = vacuum path transmission
$= f\tau_c\tau_2$
τ_g = gas cell gas transmission
τ_2 = transmission of optics unique to vacuum path
τ_1 = transmission of optics unique to gas path
τ_c = transmission of optics common to both paths
f = band pass filter

$$\overline{(\tau_1/\tau_2)}\equiv\int f\tau_c\tau_1 dv\Big/\int f\tau_c\tau_2 dv$$

The calculated V or DV transmissions described above are then used in the convolution process that calculates the simulated signal. This step will be reviewed in more detail later. BANDPAK, and LINEPAK require a minimum of user inputs facilitating ease of operation. The simplistic manner in which either code is called makes it possible to easily perform complex retrievals as will be discussed later.

8.2 Spectral Line Parameters

Accurate spectral parameters were needed for both the band and line-by-line models, and all spectral line parameters were carefully reviewed. Other similar measurements such as an O_2 continuum model [Orlando et al., 1991] for use in the H_2O and NO_2 channels were also carefully evaluated. The line parameters not only had to be for atmospheric conditions, but also had to include parameters needed to model the gas cell spectra; for example, self broaden HF half-widths are required to model the HF gas cell. The improvement of the line parameters was an ongoing effort for the HALOE software team during the HALOE mission. They were updated to 1992 HITRAN for V19, including some modifications provided by Dr. Chris Benner of the College of William And Mary.

8.3 Spectral Filters

Accurate knowledge of the spectral filters is crucial to the calculation of the simulated transmission. To determine the characteristics of the filters, a detailed analysis of each filter was undertaken [Harvey, 1989]. This analysis included carefully examining out-of-band spectra to search for possible radiation leaks using data taken on a Fourier Transform Infrared Radiometer (FTIR). The in-band spectra of each filter were also studied to determine the change in position and shape of each filter as a function of temperature. It is this temperature dependent data that is used to shift each filter as a function of filter temperatures for each event. For the band model the absorption/transmission tables are actually composed of multiple tables each calculated for a different filter temperature that together cover the range of filter temperatures expected during operation. During the Level 2 processing the values from the tables are interpolated to the filter temperature for a given event. For the line-by-line model the filter function is calculated for the channel's filter temperature for the event and the spectral integrations are performed using this filter function.

8.4 Gas Cells

The HALOE gas correlation channel cells provide the sensitivity for HALOE to measure NO, CH_4, HCl, and HF [Russell et al., 1993]. The basic principle of gas filter spectroscopy is that the incoming solar energy is split into two parts; one includes a gas cell with the target gas and the other has only a vacuum path. The difference between the signals from these two paths produces a signal that is extremely sensitive to a weak target absorber like HF since the gas cell spectra act as a very specific filter to increase the sensitivity to the gas. Simulations of the wide band and narrow band transmissions are used to calculate the simulated HALOE signal as part of the retrieval process that will be discussed later. Clearly, if the simulated gas cell spectra are incorrect due to bad line parameters or the use of erroneous gas cell fill conditions, the retrieved mixing ratio will be in error because the simulated spectral lines will not correlate correctly with the simulated lines for that gas in the atmosphere. Also, if there is a gas cell content error, the spectral lines in the gas cell will not coincide with the corresponding atmospheric lines because of Doppler shifts, and simulated gas cell path transmissions will have errors that depend on the Doppler velocity. An in-orbit calibration technique was developed to help determine the gas cell contents, and this was used to determine if there were any changes in the cell conditions during the mission life of HALOE; this technique is described in a paper on the accuracy of atmospheric trends inferred from HALOE data [Gordley et al., 2009].

Prior to launch, test gas cells were studied over time to determine the contents and stability of the cells; a gas cell life test program [Sullivan et al., 1983] supported a series of tests to determine the effects of long term aging, temperature extremes, etc. on the gases in the cells. This test program produced a wealth of information and indicated that the gas in the gas cells should remain unchanged during the long HALOE mission. One note: as a result of this pre-launch test program, the HF in the HF channel gas cell was found to form polymers when subjected to cold temperatures. To prevent the formation of these polymers, a heater was installed on the HF gas cell to maintain the cell temperature at a value above polymer formation during the mission. The HALOE gas cell conditions are contained in the channel info file shown in the Level 2 flow chart as shown in Figure 4-1. These values were obtained by the previously mentioned pre-flight measurements. Table 8-1 shows the cell conditions used in the V19 algorithm. Note that the mixing ratios are by volume. The neutral gas in all cases was nitrogen, N_2.

Channel	**Pressure (mb)**	**Mixing Ratio**
NO	101.325	0.09
CH_4	607.95	1.0
HCl	101.325	0.10
HF	202.65	0.48

TABLE 8-1

8.5 Aerosol Model

Another important piece for the transmission calculation is the aerosol model. In June 1991, 3 months before launch, Mt. Pinatubo thrust tremendous amounts of aerosols into the stratosphere. The magnitude of the aerosol loading required that the effects of the aerosols be included in the inversion code for the radiometer channel retrievals to be accurate for the lower stratosphere where the aerosol extinctions were large. To determine the aerosol extinctions, the inversion code makes use of the NO gas correlation channel DV/V signal formulation. As will be described in Section 13, the ratio of the measured DV signal divided by the measured V endoatmospheric signal is nearly insensitive to aerosols because the aerosol absorption is present in both the DV and V signals and ratios out. NO is first retrieved using the NO channel DV/V signal (also known as the modulation signal), and then the NO V signal is used to retrieve the aerosol extinction for the NO channel wavelength (5.26 microns). A model is then used to extrapolate the aerosol extinction measured at the NO channel wavelength to the wavelengths of the other channels. The technique used to extrapolate the aerosol extinction is described in [Hervig et al., 1995]. During times with levels of high aerosols, this approach is very important for the radiometer channels. One caveat about the aerosol model is given. As for any retrieval, the NO aerosol retrieval exhibits noise as the signal gets low; modeling a noisy aerosol profile for use in other channels imparts noise onto those channel retrievals. To help eliminate this artifact, the model aerosol profiles used in the other channels are strongly decreased with altitude using a ramp function above, where the aerosol profile is deemed reliable. This interfering aerosol profile is contained in the Level 2 file, and the aerosol extinctions used in the retrievals of other species can be judged along with the retrievals.

8.6 Diurnal Model

The last element needed in the transmission model is the inclusion of the nature of gases that exhibit diurnal behavior [Natarajan et al., 2005]. The HALOE species that need a diurnal gradient included in their retrieval are O_3, NO and NO_2. This model is needed because an occultation measurement views at sunrise or sunset, when a photochemically active species is changing, often leading to significant horizontal mixing ratio gradients.

The model calculates a fractional change per arcdeg along the observation direction as a function of altitude to be applied to the retrieved mixing ratios in the onion peel shells above the current layer. This allows the concentration along lower altitude observation paths to be accurately modeled using retrieved values for upper layers. There are two coefficients for each layer, one for the near (instrument side) and one for the far side of the tangent point. These coefficients are passed into the BANDPAK or LINEPAK routines where the coefficients are used to model the mixing ratios in non-tangent layer intersections of shells above the observation tangent point. It is noted that the type of event (rise or set) is needed in this calculation; for V19 the HALOE rise/set flag was used, but it is not always accurate. Due to the orbit of the spacecraft, HALOE will see an event on some occasions that is not of the same type as the local (seen from the earth's surface) rise/set. Future versions of the algorithm will denote the local rise/set, based on instrument line of sight.

9 Field of View (FOV)

The field-of-view (FOV) functions for each channel were obtained during prelaunch instantaneous field-of-view (IFOV) tests made in 1988 in which an illuminated slit was passed in front of the HALOE telescope. The measured 2-D FOV was reduced to a 1-D FOV with a point spacing of 1/15 arcmin for use in the retrieval software since the level 2 processing only does a vertical one-dimensional FOV convolution. A 1-D FOV function is sufficient because the curvature, due to the geometry of the onion peel layers, is insignificant over the FOV width. The FOV functions for all the channels are contained in data statements in the routine GETFOV.F. This data is plotted in Figures 9-1 and 9-2. Two points are noted from the plots. First, the H_2O filter function is not nearly as smooth as the others because of residual H_2O in the interferometer optical bed; simulations show that these features do not cause a problem in the use of the function filter. There is also a small zero offset in the wings of the FOV functions that is negligible. For the DV channels, the gas path FOV is almost identical to the vacuum path FOV, and the V FOV measurement is used in the simulated signal convolution. Further, because the gas correlation channels view the Earth's atmosphere through two optical paths, a FOV mismatch function exists for those channels. Those functions were developed in 1989 prior to launch (see Don Richardson and Larry Gordley, "Determination of the field-of-view (FOV) and FOV mismatch functions for the HALOE channels", internal document of the HALOE Project Archive, NASA Langley). Its functional form was checked later from in-orbit measurements to see if any changes could be determined that would affect long term trends (none were found) [Gordley et al., 2009]. A correction for the mismatch is performed in the level 1 processing based on the 1989 pre-flight analysis.

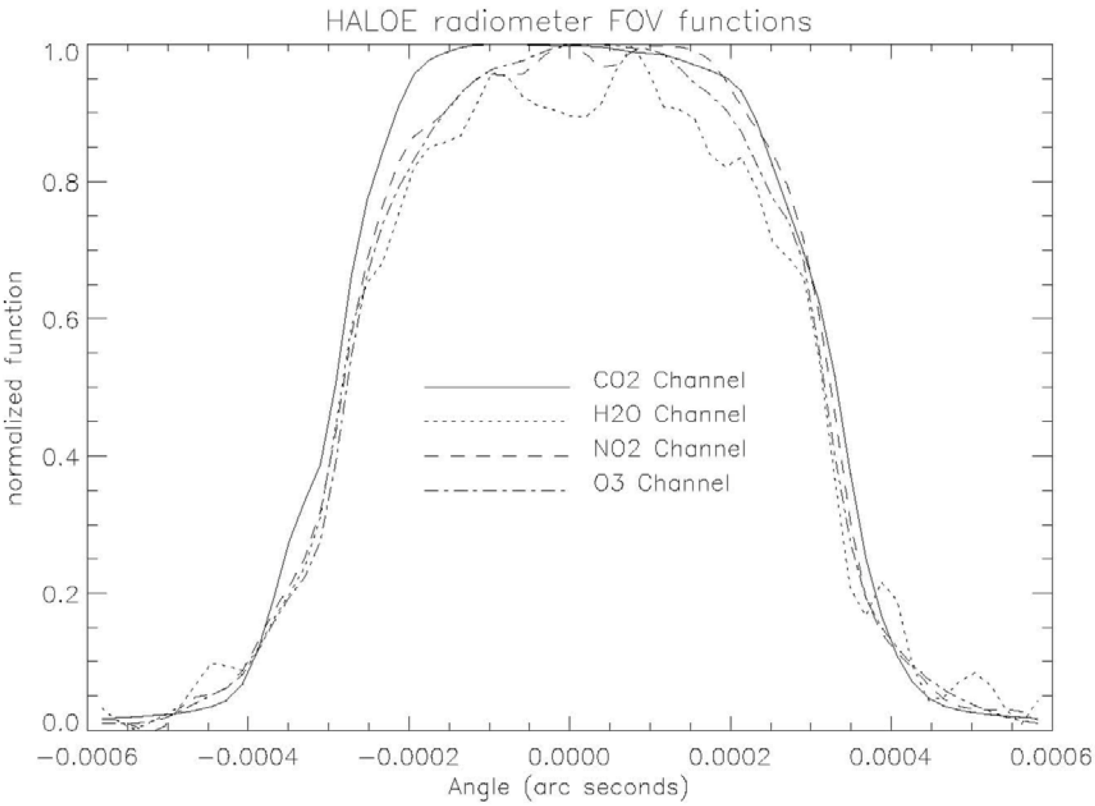

Figure 9-1
FOV functions for radiometer channels

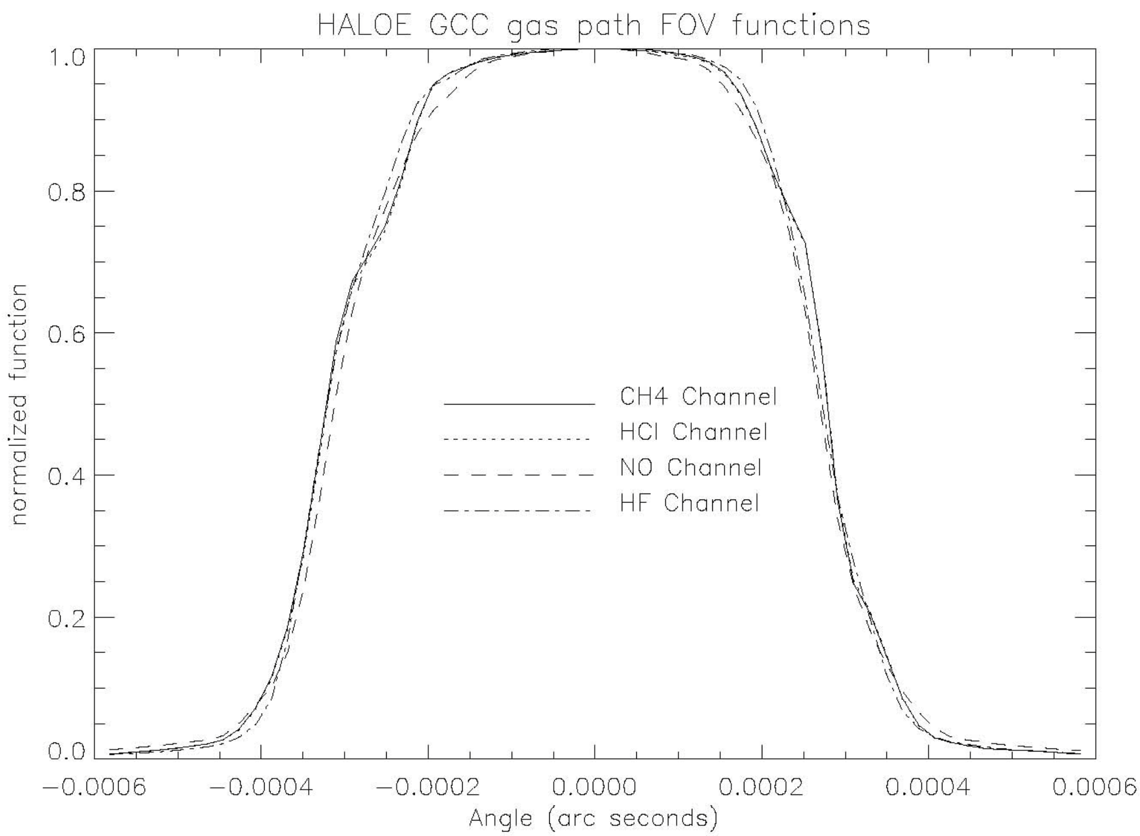

Figure 9-2
FOV functions for gas correlation channels (GCC)

10 Solar Limb Darkening Curves

The HALOE instrument tracks the solar image as the sun rises or sets through the Earth's atmosphere [Mauldin et al., 1985]. The instrument locks its FOV onto the solar image at some commanded distance down from the top edge that can be varied event to event; the lockdown was set at 8 arcmin from the top edge of the sun for most of the HALOE mission, but this lockdown angle does vary slightly during the event. To specify the exact position needed in the Level 2 software, there is a boresight position for each tangent altitude (each signal measurement) contained in the Level 1 file (and Level 2 files). The HALOE sunsensor assembly maintains a very precise tracking of the solar image through the atmosphere by focusing the solar image on an array of 256 diodes and by using that array readout to keep the position of the solar image on the array at the commanded location. Because the position of the solar image on the array must be accurately known, the FOV of the diodes was very accurately measured in prelaunch tests. In addition, because of atmospheric refraction, the solar image actually "squashes" (flattens) during an event, which causes the FOV to gradually slide down along the solar intensity curve. Exact knowledge of the solar intensity curve is required to calculate the simulated HALOE signals used for the retrievals. To obtain this information, during each event HALOE makes exoatmospheric scans of the sun. A total of 9 such scans are made, and the average of these for each channel is contained in the Level 1 and Level 2 files. These intensity curves are convolved with the other functions needed to simulate the HALOE signal. Because the solar limb darkening curves (SLDC) are a function of wavelength, each of the HALOE channels has a slightly different curve; for example, the HF channel at about 4178cm^{-1} is much more rounded then the O_3 channel curve which is near 1015cm^{-1} (See Figure 10-1).

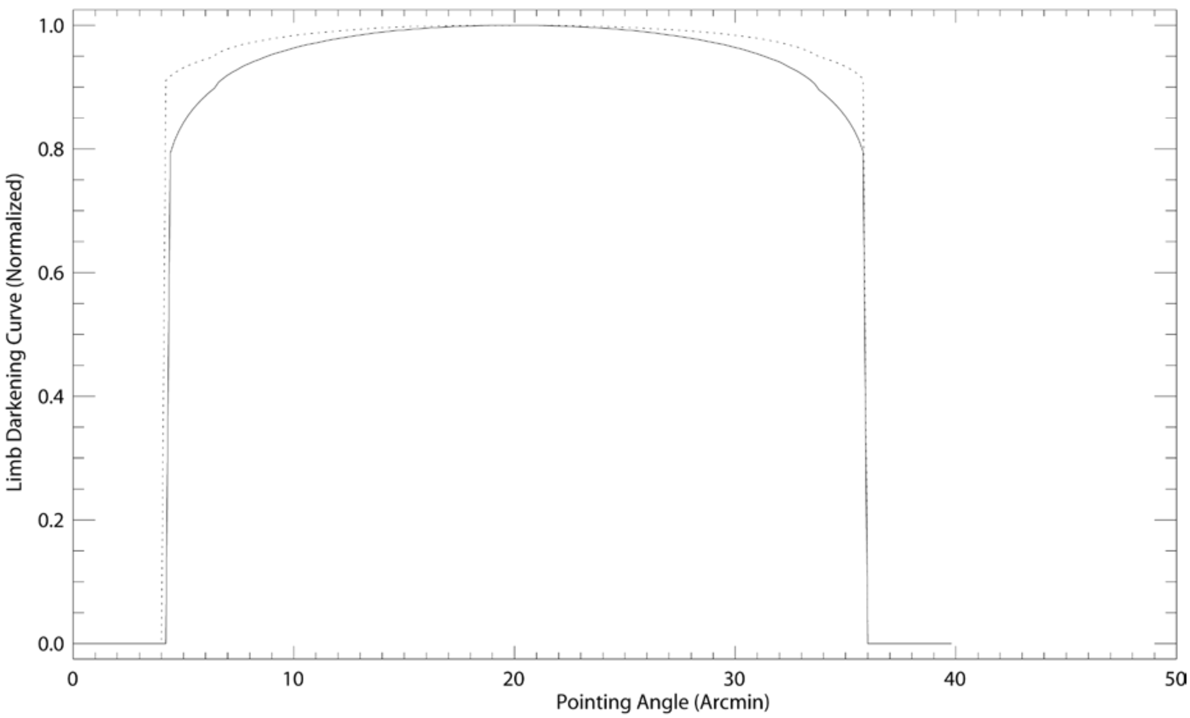

Figure 10-1
Example of HF and O_3 solar limb darkening curves.
The solid line is the curve for HF. The dotted line is for O_3.

Looking closely at the curves, there are small dimples about 2 arcmin from either edge of the curves. During the deconvolution of the SLDC data in Level 1 processing, the sharp edges of the HALOE measured data induce severe ringing. This artifact is removed by splicing on theoretical solar limb darkening curves [Allen, 1976] at the edges; the dimple is where the real and theoretical data are spliced together. Through most of the mission, the FOV was locked down at 8 arcmin from the top edge of the solar image; this was done to stay near the center of the solar intensity curve and hence minimize the impact of any FOV movement on the solar source function. Since the lockdown angle from the top edge is always greater than 2 arcmin, the dimple artifact does not impact the retrievals.

A few other details are noted about the SLDC data. When the HALOE measured SLDC data are not useable, the Level 1 code substitutes the theoretical “Allen” SLDC for the given channel. This substitution was done in about 1 ½% of all events because of data taking constraints imposed by serious issues with the UARS tape recorder. This use of the theoretical SLDC does not produce any obvious artifacts in the HALOE retrievals since the curve is close to the actual solar curve. Plus, the curve is used to predict the effective source function fractional change, not absolute signals. In addition, the Level 2 processing failed in a few instances due to corrupted SLDC data. These days were rerun “event by event” and the SLDC for another event (same mode) was substituted. Just as in the case of the theoretical curve substitution, this step does not impact the data; a record of substituting one event’s SLDC for another is contained in the document entitled “V19 processing details” that is on the HALOE internal documentation site and which has been archived along with other project documents.

During the first years that HALOE collected data, the sunspot cycle was at its peak and HALOE viewed several large sunspots. Because the Sun-HALOE orientation is changing during a SR or SS event the path across the Sun that is scanned by HALOE during its solar-scan mode may not be the same location as when the Sun is being tracked during the actual data period. In other words, a sunspot may come into view that was not measured exoatmospherically (or vice versa). These sunspots can cause errors in the retrievals because they will lead to an incorrect modeling of the solar source function. Sunspots impact the HF channel measurements the most, both its HF profiles and its HF aerosol extinctions.

As mentioned above, exoatmospheric scans are used to determine the solar curves. However, for the gas correlation channels, the DV measurements across the Sun do not produce a solar image. Since these DV measurements are correlations with the species of interest, they should be flat unless the Sun itself contains some molecules that induce a signal; indeed, there are sometimes small features in the signals that are believed to be due to some species in the Sun. Also, as the FOV moves off the sharp edge of the solar disk, there is a signal induced in the DV measurements due to a slight FOV mismatch between the signal gas and vacuum path V signal. Scans across the solar edge were used to check for accuracy in FOV mismatch calibrations and changes in the HALOE FOV mismatch with time as part of HALOE in-orbit calibration. The calibrations were verified and no significant changes were detected during the mission.

11 Refraction

A complication for the retrieval process is refraction, which causes the ray paths to bend as they pass across the limb of the atmosphere. The geometrical calculations done in the BANDPAK and LINEPAK models determine the actual ray paths, and, through the use of internal data handling, the effects of refraction are accounted for in the transmission calculations without the user needing to worry about it. In addition, the convolution of the FOV over the SLDC is further complicated by the fact that the solar image is squashed due to atmospheric refraction. Exo-atmospherically, the Sun appears round as viewed by HALOE, but as its image moves lower and lower in the atmosphere the solar disk appears increasingly “oval” shaped (see Figure 11-1). Exoatmospherically, the solar disk is about 32 arcmin across; however, by the time that the top edge of the Sun is at a 30 km tangent altitude, its image has already shrunk to about 60% of that value (in the vertical). This squashing means that the HALOE FOV effectively expands vertically on the solar image. In addition, because the FOV position is locked relative to the top edge of the solar image as seen by HALOE, the FOV is moving downward across the image as it is being squashed. Because the solar image is not of uniform brightness (being brightest near the center and then rolling off toward the edges) the solar source function changes with altitude as the FOV moves along the solar image. One can see this effect by plotting the HF V signal as a function of altitude. At higher altitudes the atmospheric absorption is less than the increase in the signal due to the changes in the solar function. The signal actually increases slightly with decreasing altitude before atmospheric absorption becomes the more dominant effect. While the endoatmospheric V signal divided by the exoatmospheric V signal is frequently referred to as transmission, the changing solar source function means that these signals are not true transmissions; see the description of “refraction functions” in Section 14 for a way to obtain transmissions. The effects of refraction are accounted for in the retrievals during the convolution of the simulated signals by working with the refraction angles and the true angles to the un-refracted Sun. It is worth pointing out that the 8 arcmin lockdown permitted HALOE to sound lower into the atmosphere than, for example, when a 16 arcmin lockdown was used. This circumstance is because the FOV slides off the bottom of the solar image (i.e., the image is refracted above the FOV) more quickly for the 16 arcmin lockdown.

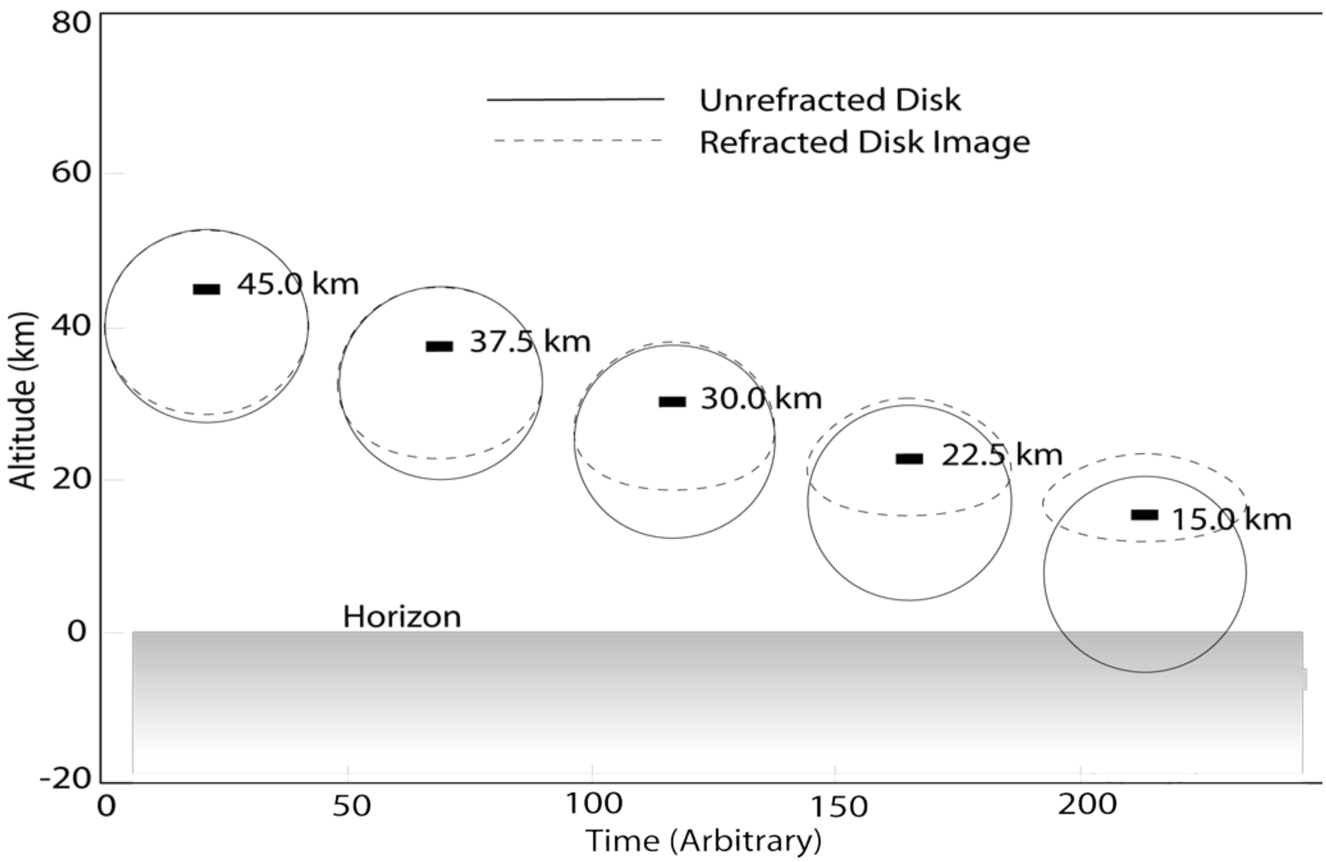

Figure 11-1
Squashing of the solar image due to refraction

To account for the solar squash phenomenon in the convolution process, the relationship between the apparent ray paths and the actual ray paths is employed. This relationship allows each angular point in the FOV function (61 points with a 1/15 arcmin spacing) to be traced back to the location on the unrefracted solar image that the FOV is actually viewing, and it permits the FOV to be "mapped" onto the solar image as a function of tangent point altitude. At lower altitudes this accounts for the FOV spreading out over a larger portion of the sun. Note that the effective change in source intensity is due to only a change in what part of the solar image is observed. It is not due to a focusing effect. That is, if the unrefracted image had a constant intensity (radiance) over the entire image, and the FOV stayed entirely on the image, refraction effects would not change the source function. The reason is that although the area of the Sun illuminating the instrument aperture is increasing, the effective solid angle subtended by the aperture is decreasing proportionately. This relationship is a consequence of the "Brightness Theorem".

12 Gaussian (or Accounting for Removal of the Butterworth Filter)

The removal of the electronic Butterworth filter in the Level 1 processing induces ringing in the HALOE signals. The signals are smoothed with a Gaussian function to reduce the ringing. In order for the simulated signals to be exactly compared to the measured signals, the simulated signals are smoothed with a Gaussian that matches the one used in processing the measured HALOE signals. For this step to be performed in Level 2, the 1σ widths of the Gaussians (1σ value for each channel) must be passed to the Level 2 code; therefore, these values are contained in the Level 1 files and are read in with other Level 1 data during Level 2 processing. The smoothing in Level 1 is carried in time but in Level 2 it is in angle. Therefore, the values used in Level 2 are a function of solar sink rate and hence change from event to event, so they are read in for each event. The 1σ value of the Gaussian is in units of arcmin and must be changed to km for use in the calculation of simulated signals in the Level 2 code. The altitude subtended by the Gaussian is not a constant over the profile, although the variation of the angle with height is small. The 1σ value is converted to km using the geometry at a tangent altitude of 45 km (see routine SETGAUS). The code uses these widths in an Erf function as the convolving function. Although the Gaussian smoothing effect is small for the simulated signal, it is included to correctly model the HALOE signals. The 1σ values (in arcmins) are also in the Level 2 files as items 41-52 in the event header portion of the file.

The Gaussian smoothing of the HALOE signals is separate from the additional signal smoothing that is applied to reduce the signal noise at high altitudes. That additional smoothing is applied to the V signals above a certain altitude, depending on the channel: CO_2, 81km; H_2O 65km; NO_2, 50km; O_3, 65km; CH_4 V, 80km; HCl V, 80km; NO V, 80km; HF V, 80km. The parameters that specify this smoothing are contained in the Level 1 and Level 2 files and are listed in Appendix 3. There is a small region below those threshold altitudes, where the smoothed signals are feathered into the unsmoothed signals. The lockdown angles are also set to mean values over the altitude range where the signals are smoothed, in order to further reduce ringing in the retrievals where they are used in simulating the signals; the constant lockdown angles are feathered into the measured lockdown angles over the same altitude range as for the signal feathering. This means that the lockdown angles are really channel dependent.

It is stressed that no measured signal processing takes place in the Level 2 code. All signal processing such as the removal of the Butterworth filter with its accompanying signal smoothing, the additional signal smoothing to reduce the effects of signal noise at high altitudes, etc. is done in Level 1. The DV offset correction is also done in Level 1. There is one caveat, however—routine RDLVL1 that reads in the Level 1 data has a section of code that appears to apply a DV offset to the 4 DV signals that are read-in from the Level 1 file. This correction actually does nothing to those signals because the formulation uses a parameter (the exoatmospheric value for each DV channel) that is read in from the Level 1 file, and it is zero. The routine does not have comments that make this clear, but the 4 signals are not altered.

13 Signal Formulation

The simulated signals can be calculated and compared to the actual HALOE measured signals, using the foregoing components. Both the measured signals and the simulated signals are formulated in ways to best perform the retrievals, and hence, there are two types of signals that must be modeled. First, the signals from the radiometer channels consist of broadband transmission measurements. The second type of signals is from the DV channels, is more complex and requires a line-by-line code to simulate the wide and narrow band terms.

The HALOE and simulated V signals are divided or normalized by the respective HALOE and simulated exo-atmospheric V signals, or V0, to forming V/V0 and helping to remove any unknown artifacts. Many problems that might otherwise have to be considered are “ratioed-out” when comparing normalized signals. The normalization of the signals is different for the gas correlation channels. In that case the HALOE signals are divided by the measured endoatmospheric V signals, not the exo-atmospheric values; thus, the signal form is DV/V. Similarly, the simulated signals are divided by a simulated endoatmospheric V. The reason for this approach is that the aerosol absorption is essentially a continuum across the bandwidths of the channels and dividing by the endoatmospheric signals ratios out the aerosol absorption. Thus, the retrievals using these channels are essentially insensitive to aerosol interference.

14 Calculation of Simulated Signal

The next step in the retrieval process is the calculation of the simulated signal. In this step the calculated transmission profile, the channel FOV, the solar limb darkening curve, and the Gaussian smoothing function are all integrated together. The signal is simulated as follows.

First, a transmission profile is constructed that is composed of simulated transmissions and scaled HALOE signals. For the rays that pass through tangent layers that have been retrieved, the transmissions are those values calculated by either BANDPAK or LINEPAK as the onion peel process moves downward. For rays viewing below or above a layer that has been retrieved, the software scales HALOE signals to the simulated signals and extends the transmission profile downward/upward to allow integration in the lower/upper half of the FOV function. This consideration is one reason why the onion peel is repeated three times, retrieving the profiles down thru the onion peel layers, and then going back to the top and doing the retrieval again and then once more. On the second and third passes, the code scales the previously iterated transmissions instead of the HALOE signals. Any bias due to scaling the HALOE signals has been effectively removed by the time of the third pass downward.

The simulated signal is computed next, and it consists of a multiplication and integration of the transmission profile, the FOV function, and the solar limb darkening curve. There is a different FOV lockdown position for each tangent altitude, since the FOV moves about slightly on the solar image. For each tangent altitude the FOV function is centered on that altitude’s lockdown value. The FOV function is an array of 61 elements and the integration across the solar image is performed using these FOV angle positions. To account for the refraction that causes the FOV to spread out across the solar image, the non-refracted position on the solar disk is determined for each of these points. The algorithm does a linear interpolation between the nearest two points on the solar curve for each FOV angle position. The point spacing was made small enough to accommodate linear interpolations. The solar intensity at each FOV point is multiplied by the FOV function value and the appropriate transmission value (interpolated onto the FOV grid using a 2nd order interpolation). The sum of all such steps across the 61 FOV points constitutes the first step in calculating the unnormalized simulated signal. For the radiometer channels the simulated signal is normalized by dividing by a simulated exo-atmospheric signal that is calculated in exactly the same manner, except that there is no atmospheric transmission or Gaussian smoothing. This normalization eliminates odd units that result from the convolution step. For the gas correlation channels the DV (difference) signal is the integration over the constant*(τ(wide) – τ(narrow)) term discussed in Section 8a with the solar limb darkening curve and the FOV. The normalization of the simulated DV signal is performed by divided by the channel's simulated exo-atmospheric V signal, as in the case of the simulated V signal. As before, this step is performed to remove the odd units resulting from the integration and is only performed to force the signals to be more realistic looking. In actuality, the signals are divided by V0 or V to put them in a useful formulation, as described in the following paragraphs; this means that the normalization step could have been omitted. For example, both the V and V0 terms are normalized for the radiometer signal formulation (see following), but its effects go away when the ratio, V/V0, is obtained.

The last step in calculating the simulated signal is one additional convolution. The removal of the electronic Butterworth filter (low bandpass filter) introduces ringing in the signals, due to the HALOE signal processing of Level 1. To reduce this effect, a Gaussian smoothing in time is applied to the HALOE signals of Level 1; its 1σ value is contained in the Level 1 files and then read by the Level 2 software, whereupon it is converted to a 1σ value in altitude. Each event has a different Gaussian 1σ value because it is dependent on the sink rate, or the solar image setting through the atmosphere as described in Section 12. To model this in the simulated signal, a profile is constructed that is composed of the results from the first step (the convolution of the transmission, FOV, and solar limb darkening curve). If that value is missing (i.e., from first downward pass), the HALOE signals are scaled just as in the previous step except that the HALOE signals are scaled using the signal profile of the first step instead of the transmission.

To expand on the convolution process, the first step simulated signal profile of the first step is multiplied by a Gaussian and an Erf function that uses the 1σ value. Note that the calculation of the simulated exo-atmospheric V signals does not include this step; it is unnecessary because the lockdown values in Level 1 are set to a constant at high altitudes for the radiometers, where the exo-atmospheric values are calculated. For the DV/V channels the lockdown value is not set to a constant for the range of altitudes, where the associated simulated exo-atmospheric values for the V signal are calculated. A very small error may be introduced by not applying the Gaussian, and that prospect may need to be reviewed. Finally, the last step of the process is to divide the simulated V by V_{exo} or to divide the DV signal by the simulated V, if it is a DV channel. Then, the HALOE measured signal is changed into its proper form: V/V0 or DV/V for the given channel.

To aid in the analysis of the HALOE signals, a "refraction function" is included in the Level 2 files. This channel/altitude dependent function is the convolution of the FOV, solar limb darkening curve, and the Gaussian smoother. A division of the V signals by this function accounts for refraction and produces a transmission profile. There is one value for each tangent point altitude for each channel. For example, item 140 in the Level 2 file data records, "RF CO2", is the "refraction function" for the CO_2 channel. There is also a similar parameter in the Level 1 files called the "source function" (items 66-77).

15 Retrieval Steps

The Level 2 software cycles through the following steps for each event. First, a routine named (appropriately enough) WHEN_FOV_OFF_SUN is called. This routine determines the altitude at which the FOV begins to move off the bottom of the Sun as the solar image squashes due to refraction; the altitude depends on the lockdown angle – the angle from the top edge of the solar image for locking onto the FOV. This altitude is then checked against the bottom good data flag altitude that was read in from Level 1. A final low-altitude, good data flag is then determined to make sure the retrievals stay above both of these altitudes; i.e., the higher value is used with some additional padding in altitude. The code that does the comparison for the Level 1 good data flag (GOOD_DATA_ALT_LOW) and for the altitude where the FOV begins to move off the bottom of the solar image (ZA_OFF_SUN) is rather complicated and needs to be checked further for a best determination of the lowest possible altitude. For example, algorithms for sounding into the upper troposphere may need to be updated because of the desire to obtain results at the lowest possible altitude, where the FOV slides off the Sun. The bottom good data flag for V19 was set to clearly avoid regions where the data are highly questionable.

After this initial check of the good data range, the software calls the routine SETUP_FOR_CHANNEL that does just what its name implies. It arranges information that is needed for the retrieval. It calls the routine GET_ZA that calculates the tangent layer scheme, based on the inputs supplied by the user via the control file. This tangent layer scheme is a subset of the values from the Level 1 file that ranges from 150km to 3.0km in increments of 0.3km and is based on extensive studies to determine the best scheme for the retrievals from each channel. For example, the tangent layer scheme for the aerosol retrieval goes from 90.0km to 3.0km in 0.3km steps, whereas the scheme for the HF DV retrieval covers the same altitude range but in increments of 3.0km. The software calculates the tangent layers and makes sure that the retrievals do not go below the good data flag (see above). In the case of the CH_4 DV retrieval the good data flag is set so that the retrieval does not go below where the DV signal saturates (near 100mb). The software shifts the tangent layers downward so that the lowest point matches the good data flag and "pads" the bottom with the few additional tangent layers needed for the signal integration step, which requires layers below the last retrieval point and which are composed of scaled HALOE signals.

Next, Gaussian weights are calculated for the integration of the simulated signal, based on the 1σ smoothing values from the Level 1 file. The explanation of just how the Gaussian is used to calculate the simulated signals was contained in the Section 14.

There is a digression at this point about the COMMON BLOCK named ALL_LVL1DAT that is used in the Level 2 code. It contains the information that is read from the Level 1 file and has arrays of 491 points for each parameter going from 150km to 3.0km in 0.3km increments. Data such as pressure, temperature, the two Doppler velocities (spacecraft-to-Sun and spacecraft-to-atmosphere), etc. are specified for each layer. In addition, each layer has a latitude and longitude to remind the user that the measured profile is not strictly from just a single location; i.e., as HALOE makes its measurements, it is continuing to move around the Earth and the Earth is continuing to rotate relative to the orbital plane. A routine named GET_LEVEL1_SUBSET pulls the values from these full arrays and loads another COMMON BLOCK named LVL1DAT that has the same parameters (plus one additional), except that the data is in the tangent layer scheme for the retrieval. The role of the one additional parameter, the true angle array, is addressed in the description of PATH_MASTER that follows.

The geometrical calculations used for the onion peel retrieval are done next with a call to PATH in BANDPAK via a routine called PATH_MASTER. In addition to setting up the geometry, the routine also calculates the refraction angles that are used to determine the true direction of the Sun (not its observed position); the true angles and corresponding apparent angles, are loaded into the LVL1DAT COMMON BLOCK. The PATH_MASTER routine also sets up the required array pointers, etc., that are needed for the interleave process.

The setup of items needed for the retrievals continues with the selection of the mixing ratios and aerosol extinctions used to initialize the forward model. For each tangent altitude a value for each interfering species is needed as well as the target species. These values come from the climatological mixing ratios selected for the event from the climatological file; as the various retrievals proceed, the climatological profiles pulled from the file for the event are replaced with retrieved profiles so that after all the retrieval steps the products are independent of climatology (except for the minor interfering species N_2O, as noted above). The assumed target species profile, as will be discussed later, does not bias the retrieval but is essentially just a good estimate for getting the retrieval started.

After the initial setup of the parameters needed for the retrieval, one of two routines is called. If there is a mixing ratio or aerosol retrieval to be done, the routine ONION_PEEL2 is called; if a T/P retrieval is to be done, PTRET is called. The routine ONION_PEEL2 is described first. There is one last bit of the initialization process though; it checks the tangent altitude array and, based on the user inputs in the control file, decides what altitude to start the retrieval. If the starting altitude in the control file is positive, the code logic uses that value as a starting altitude; if the starting altitude is negative, the code checks the signal levels (starting at the top) for each of the tangent layers and picks the starting altitude where the signal becomes larger than the channel noise level (noise values are listed in the routine OPTION). The values for starting the DV retrievals are all positive in the control file. This outcome is due to the nature of the DV signals; they can be negative or positive depending on the signal induced by the target and interfering species.

Once the selection of starting altitude is made, ONION_PEEL2 calls the routine RETRIEVE_MIX to actually do the retrieval. The loop over tangent altitude is in this routine, beginning at the starting altitude and moving downward. However, this loop is actually inside an additional loop that is performed 3 times, as specified in the control file. This outer loop is the “FOV loop”, where the retrievals are repeated two additional times to remove artifacts of the FOV integration that are due to estimating the transmission profile below the current tangent layer. There are also additional retrieval iterations that are made within the tangent altitude loop until a convergence is achieved. Let us review the basic steps that are involved in retrievals for a single layer.

As the retrieval proceeds downward, the retrieved and interfering profiles above are required to calculate the transmission through the outer shells above the current tangent layer. As discussed in detail in Section 8f on DIGRAD, for the photochemically-active species this step is somewhat more complicated because their profiles above the current tangent altitude are varying with the local time for the sunlight at sunrise and sunset. Because the observed path intersects each level at a different local time, DIGRAD is called and determines horizontal mixing ratio gradients for each higher concentric layer and accounts for the sunlight induced changes for each layer’s diurnal species. These gradients are input into the forward model to permit a more accurate transmission calculation in the upper shells by using tangent point retrieved mixing ratios and horizontal gradients to estimate mixing ratios at the observation/layer intersection points.

The single most important aspect of the retrieval algorithm is an accurate forward model of the signal. The two models that are used, BANDPAK and LINEPAK, were discussed earlier. The RETRIEVE_MIX routine picks one of these models as specified in the control file. For data version V19 the radiometer channels used BANDPAK and the gas correlation channels used LINEPAK. Because of computational restrictions the tangent layer scheme for the channels using LINEPAK was much coarser than for the radiometer channels. Also, because of the coarse spacing for the gas correlation channel retrievals, only one interleave was used. By utilizing either BANDPAK or LINEPAK a transmission value is calculated for the current tangent layer based on the latest guess mixing ratio or aerosol extinction. Both a narrow and a wide transmission term is calculated by LINEPAK for the gas correlation channels.

Next a call to GET_HALOE_SIGNAL is made, and the HALOE signals for the relevant tangent level observation are pulled from the LVL1DAT COMMON BLOCK and used to create the functional form of the signal that will be simulated in the retrieval process. For the radiometer channels the V signal measurement is divided by the exoatmospheric V (or V0) to give a V/V0 signal measurement. For the gas correlation channels the HALOE measured DV signal is divided by the observed, endoatmospheric V signal to yield a DV/V signal. These HALOE signal functions are compared to analogous simulated signal functions during the retrieval process. Therefore, great care must be made in formulating the corresponding simulated signal function.

The routine TEST_FOR_CONVERGENCE is called which in turn calls the routine DETERMINE_SIM_SIGNAL. Following subsequent calls to other routines, this routine uses the calculated transmissions and scaled, HALOE signals to create a full transmission profile. As described in detail above, the code then convolves the full transmission profile with the FOV and the solar limb darkening curve using the routine CONV_TRAN_FOV_SLDC. Then, the GAUSSIAN smoothing function is convolved over the profile produced in the transmission/FOV/SLDC convolution step. The simulated signals are then combined to produce a simulated signal that is comparable to the actual HALOE measured signals.

The next step in the retrieval process is to compare the HALOE measured and simulated signals and make an estimate of the target species mixing ratio (or in the case of the aerosol retrieval, its extinction), using the routine named OPTIMAL_EST. The logic of this routine has undergone a number of modifications and adjustments. A brief overview is presented here. The very first time the routine is called, there has only been one forward signal simulation, so it is not possible to determine the sensitivity of the simulated signal to changes in the target species. Thus, it is not possible to use the signal sensitivity to estimate the amount of the target species that would allow the simulated signal to match the HALOE measured signal. Therefore, for the first call to the routine, a new guess is made that is 10% greater than the initial guess; note that the top layer's first guess mixing ratio value is the ONLY use of climatology for the target species. The new guess is used to make an updated simulated signal estimate for the 2nd call. At this point you have a new simulated signal as well as the old signal, and a sensitivity estimate can be calculated and used for making the next guess. Basically, two equations are used for making the first estimate of the new guess.

The first equation is (with the mixing ratio retrieval as the example)

(15-1) $$DQDS = \{Q_1 - Q_2)/(S_1 - S_2),$$

where
DQDS is the change in mixing ratio with a change in simulated signal
Q_1 is the previous mixing ratio guess for the current tangent point altitude
Q_2 is the latest mixing ratio guess for the current tangent point altitude
S_1 is the simulated signal calculated with Q_1
S_2 is the simulated signal calculated with Q_2 .

A new guess for the mixing ratio would then be given by equation (15-2)

(15-2) $$Q_{new}=Q_2 + (H-S_2)*DQDS,$$

where
Q_{new} is the new guess and
H is the measured HALOE signal.

However, there are pitfalls to this basic scheme, and the code includes various checks to improve upon this guess. For example, if the new guess is negative (not physically possible), the new guess is set as ½ the last guess. Another approach is the use of constraints to limit the amount of change and thus reduce "ringing" in the retrieved profile. The constraints are based on user-supplied parameters (see Section 18 on the control file). Each guess is constrained by weighting it with retrieval values from other independent interleave profiles. This weighting is limited to angular distances within the inherent resolution of the measurement. In effect, this approach treats each interleave profile as an independent observation to estimate results at all points within one optical resolution (angular). Other considerations in OPTIMAL_EST include a check to see if the next guess is actually bigger or smaller than any estimate already computed for the layer. If the new guess value is outside either limit, a guess is made from between the previous maximum and minimum limits. Relaxation is considered complete when the difference of successive guesses is either less than 0.1% of the guessed value, or less than 20% of estimated random noise of the retrieved value. Then the retrieval drops down to the next layer, using the value for the layer above as a first guess. Note that the mixing ratios above the top layer are set to a constant (the value of the top retrieved layer) to promote stability.

Upon completion of the retrieval of a species profile, it is output to file. Each retrieved profile also replaces the initial climatological profile for the event. The original climatological profile is scaled to the retrieved profile and used to extend the retrieved profile up to 150km and down to 3.0km. This new profile can then be used as an interferent in other channels where appropriate. As specified in the control file, some retrieved profiles are further smoothed with a cosine bell function to reduce ringing before being written out and placed in the set of climatological profiles. In particular, H_2O, NO_2, and O_3 are smoothed for V19.

16 Temperature/Pressure Retrieval

The temperature/pressure (T/P) retrieval is performed a little differently then the mixing ratio and aerosol extinction retrievals. The retrieval actually starts at 31.5 km and retrieves upward to approximately 85km. The starting altitude is referred to as Z0, where the pressure registration in level 1 should give the best agreement between the simulated HALOE CO_2 channel signals and the HALOE signals because at this altitude the first guess NMC temperature profiles are believed to be sufficiently accurate. Since the upward T/P retrieval technique requires the bottom layer to be unchanged during the retrieval process, accurate values for temperature (T0) and pressure (P0) at Z0 are essential. However, it should be pointed out that there were always small differences between the measured and simulated CO_2 channel signals near the registration window. It is generally believed that this is an accuracy limitation of the forward transmission model. For instance, when the band model transmission code in the Level 1 and Level 2 software was changed to a line-by-line model that included CO_2 line mixing (coupling), the measured/modeled signal agreement was improved. Another reason for choosing 31.5km as a starting point is that the sensitivity of the signals to temperature and pressure is quite good. In addition, starting at or above 30 km reduces aerosol interference to negligible levels. It should be noted that the input (first guess) profile is set to a constant temperature value (T0) which reduces retrieval artifacts induced by the input NMC profile shape. Therefore, above the top retrieved temperature (near 85km), the retrieved temperature profile is a constant to the top of the T/P tangent layer scheme (approximately 100km). However the output profile is a combination of retrieved results below 85 km merged with an MSIS profile above 85 km. This final profile is used for all species retrievals.

The retrieval is performed using a typical onion-peel layer scheme with 1.5km thick tangent layers, where the 1.5km spacing was chosen to help promote stability. BANDPAK, using the EGA technique, is used to calculate the transmission profile for the 31.5 km observation and the next 2 observations above. These transmissions are next convolved over the pre-launch measured CO_2 channel FOV function, the HALOE measured CO_2 channel solar limb darkening curve and the Gaussian to create simulated signals. The 3 simulated signals are then summed because we found that retrieving on a signal that is actually a function of the current tangent layer conditions and the two layers above stabilizes the retrieval. The 3 corresponding HALOE signals are also summed and a Newton-Raphson technique is used to predict a change in temperature that would allow the calculated signals to match the HALOE signals. The temperature at the top of the 31.5 km tangent layer is changed accordingly, but to maintain stability, the temperature and pressure at the bottom of the layer is not changed. Above the top of the Z0 layer, the temperatures are also changed; they are all changed by the same percentage as the temperature was changed at the top of the Z0 layer. Once the temperature profile is changed, an updated, hydrostatic pressure profile is calculated. This procedure is repeated until the convergence criteria are met. The first convergence criterion is

(16-1) $(H - S)/S$,

where H is the summed HALOE measured signals
S is the summed simulated signals.

When the absolute value of this expression becomes less than 0.0007/3, convergence is assumed; the value of 0.0007 is an estimated signal noise value and the 3 is from the fact that we are working with 3 layers. The value of 0.0007 was an early noise estimate and is different from the more recent CO_2 channel noise estimate contained in the routine OPTION.

The second criterion for convergence is based on the estimated change in temperature required to match the HALOE signals, which is

(16-2) $(H-S)/(S_p - S_c)/(T_p - T_c)$,

where S_p is the previous simulated signal value
S_c is the current value of the simulated signal
T_p is the previous value for the temperature for the layer
T_c is the current value for the temperature for the layer.

When the absolute value of this ratio is less than 1.0e-4, retrieval for the layer is stopped.

A few important things about the T/P retrievals are noted here. First, the T/P retrieval does not use an optimal estimation technique which would tend to constrain the retrieved profile toward an a priori value where ever signals approach the noise. Secondly, if there is an error in the temperature at Z0 or if there is a difference between the simulated signal and the HALOE measured signal at Z0, a spike will develop in the retrieved temperature starting at the top of the Z0 layer. For HALOE V19, there is almost always a spike of several degrees, and it is likely due to small forward model errors. However, the retrieval pulls back to the correct profile within a few km above the Z0 layer. As will be discussed below, the portion of the retrieved profile that has the spike is removed before the temperature/pressure profile is used in subsequent retrievals.

Once the convergence criterion has been met or the temperature profile has been iterated on at least 5 times, the onion peel moves up one observation level and repeats the retrieval process using three levels in the same manner as described above. The temperature at the top of the tangent point layer and the layers above are changed. The retrieval process continues upward to about 85 km where the signal to noise is small. The T/P retrieval then goes back to 31.5 km and does the upward retrieval process two more times. With each upward pass, more details are resolved. Changes that occur after the third upward sequence are insignificant.

The final temperature/pressure profile is constructed in the following manner in the routine HYDRO_TERP2, which is in the HALOERETLIB_PTRET library of routines. In retrospect, the steps to perform the hydrostatics described next should have been reviewed and simplified. Once the temperature retrieval is completed, the input level 1 temperature profile is used to extend the retrieved temperature profile down to 3km and up to 150km. This profile is composed of NCEP data up to about 50km; above this there is a climatological model to about 85km, and then above this the MSIS model is used to extend the temperature profile to 150km. The input level 1 NMC profile is merged onto the bottom of the retrieved profile between 31.5km and ~45 km to eliminate the small spike that almost always occurs. Likewise, the upper portion of the retrieval is gradually merged onto the input profile between ~75km and ~100km. Three different hydrostatic buildups are performed. First, the pressures are rebuilt upward starting at the layer above Z0 to the top of the T retrieval tangent layer scheme, 99.0km. This hydrostatic calculation is done on the same 1.5km layer spacing as the T/P retrieval and is intended to be consistent with that retrieval. Next, another hydrostatic calculation is performed that goes over the same altitude range as the previous hydrostatic buildup, but this technique calculates the pressures in between the 1.5km layers of the previous step. For example, it calculates the pressures between 31.5km and 33.0km by building pressures up from 31.5km for 31.8km and 32.1km and building down from 33.0km for 32.7km and 32.4km. This maintains the pressures at the 1.5km grid, but introduces very small discontinuities between the upward and downward builds of pressure. Lastly, the pressures above 99.3km to 150km are calculated. When this process is completed, the final version of the T profile goes from 150km to 3.0km in 0.3km layers. Note that the input Z, P and T profiles below the 31.5km Z0 altitude are not adjusted. This final profile is placed in the ALL_LVL1DAT COMMON BLOCK where it is used for retrievals of the species. In addition, the temperature and pressure profiles tagged to the climatological profiles used for the event are updated.

As described in Section 5, there were two T/P retrievals for V19. For the first retrieval, the input Level 1 T/P profile was used to extend the retrieval over the 3-150km altitude range as explained in the foregoing paragraph. For the second T/P retrieval, the first retrieved T/P profile stored in the ALL_LEVEL1DAT COMMON BLOCK was merged into the retrieval to extend it to 3km and to 150km. Thus, the final T/P profile is further weighted to the retrieval in the two merged regions; this means that the output profile is mostly retrieval as opposed to the climatological model to somewhere above 80km depending on just how different the retrieved profile is from the climatological profile. Similarly, the NCEP/Retrieval merging is weighted to the retrieval; the output T profile is mostly retrieval perhaps down to under 40km.

A few notes are added here for the user. The Level 2 code is also called during the Level 1 processing step. This Level 2 run is referred to as “lite” since only the channels needed to determine an accurate temperature profile are considered. The P/T retrieval is the main reason for running “lite” so that the retrieved T/P profile can be used to refine the pressure registration process in a second execution of Level 1. In addition to T/P, aerosol extinction (at the CO_2 channel wavelength), N_2O (climatological profile), retrieved H_2O, and CO_2 (using the model supplied by Karen Rosenlof of NOAA) needed for the CO_2 channel simulation are also written out by the level 2 code for use in Level 1. Another useful piece of information is that the Level 2 files have 3 temperature profiles in them. One is the actual retrieved temperature profile that has the spike just above Z0 and the constant temperature profile above where the retrieved temperature stopped. The index numbers for Z, P, and T are 33, 32, and 34 (see Appendix 2 on the V19 Level 2 file description). The second profile is the profile created by merging the retrieval and input profile. Its index numbers are 1 for altitude, 151 for pressure, and 150 for T. The third profile is the input profile read in from Level 1 with index numbers 1 for altitude, 9 for pressure and 10 for altitude. Figure 16-1 shows an example of these 3 profiles.

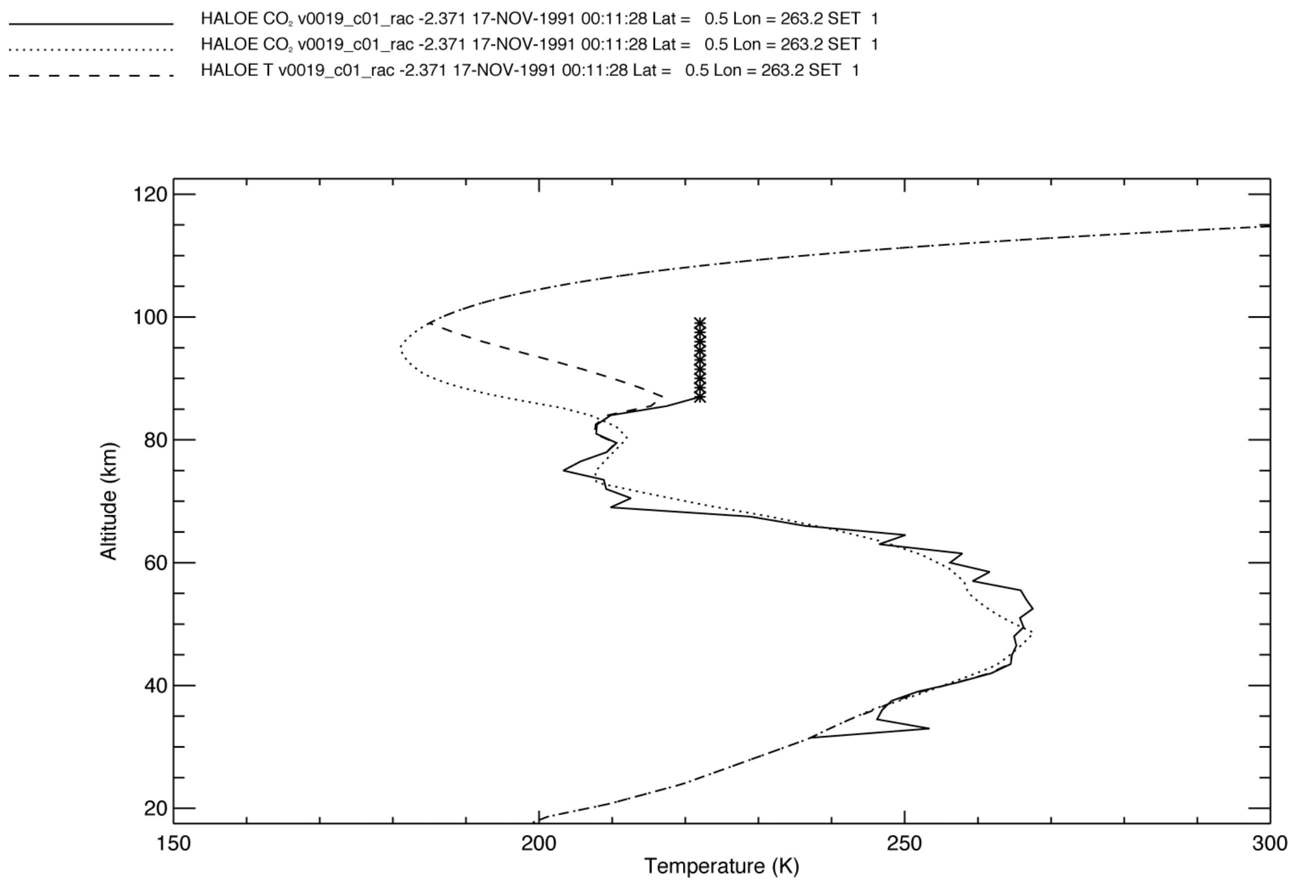

Figure 16-1
This figure shows the actual temperature retrieval (solid line), the input profile (dotted), and the merged (retrieved and input) temperature profile (dashed).

17 Precision Estimates

The HALOE error estimates are precision estimates expressed in standard deviations and are composed of several components. One component is the standard deviation due to signal noise which is obtained as part of the optimal estimation technique. A second part is the error due to uncertainties in the aerosol model and is included only in the precision estimates for the radiometer channels since the gas correlation channel retrievals are believed mostly insensitive to aerosol extinction errors. This uncertainty is equal to the derivative dq/da (change in mixing ratio with absorption) multiplied by the absorption due to the aerosol in that channel and then multiplied by the aerosol model error that is assumed to be 5%. For the temperature retrievals the first steps in the calculation of the standard deviations are somewhat different. The foregoing components are replaced by the change in temperature per change in signal and multiplied by the noise level of the CO_2 channel.

The final part in the calculation of the measurement precision involves taking the above values and combining them with the signal smoothing parameters that were used in the level 1 processing to reduce the impact of signal noise, the measurement variance, the channel absorption, the number of interleaves, and the post-retrieval smoothing applied to the profiles. A detailed review of the calculation of the precision estimates is given in Appendix 3 on precision estimates (quality numbers). That description also points out a mistake in the estimates of the temperature precision.

18 Running The Level 2 Retrieval Code

The HALOE level 2 inversion software is very flexible permitting rapid testing of the algorithm. User control is provided by a control file that is read from the runstream. This file allows the user to control/change almost every aspect of the inversion scheme. For example, the normal channel order used in the operational processing can be altered easily; this capability enables one to make test runs for a single channel or various combinations of channels. The events to be processed can also be controlled, so that an unusual or interesting retrieval result can be thoroughly investigated. Of particular importance are the many retrieval parameters for each channel that are read in from the control file; they permit the retrieval techniques to be managed by the user. A description of the parameters is given in table 18-1, and the list of values for each channel for V19 is given in table 18-2.

PARAMETER	DESCRIPTION
FORWARD	Permits switching from a retrieval to a forward model run. If 0, the code does a retrieval; for normal processing all channels have a 0. If a value of 1, the software uses the level 1 data and the retrieved mixing ratio profiles (or climatological mixing ratios if retrievals have not been done) to calculate a simulated HALOE signal; no retrieval is attempted
DIURNAL	Turns the diurnal correction on or off for any channel calculations using NO, NO_2, or O_3
FORWARD MODEL	This controls whether BANDPAK or LINEPAK is used for the transmission calculation. A 1 indicates BANDPAK, and a 2 indicates LINEPAK
AEROSOL OPTION	Flag to include aerosols in the channel (1 yes, 0 no). Also used to control which aerosol channel is used to supply the extinctions to the wavelength dependent model (-1 means use this channel for correction).
INTERLEAVES	The number of interleaves
CONVOL TRANSMISSION	Convolution flag for convolving transmission. 0 means convolve using the hi-resolution layer spacing. A 1 means do the low resolution convolution on the individual interleave spacing.
ATMOSPHERIC STANDARD DEVIATIONS	The estimated 1σ uncertainty in the mixing ratios or aerosol extinctions that is used in the optimal estimation technique.
MEASUREMENT STANDARD DEVIATION	The estimated measurement 1σ uncertainty in the signals that is used in the optimal estimation technique.

TABLE 18-1
Descriptions of V19 control file parameters

PARAMETER	DESCRIPTION
MIXING RATIO SPREAD FUNCTION	This is a weighting function used in the estimation formulation.
WEIGHTING DISTANCE	This is also a weighting function used in the estimation formulation.
SMOOTH	This controls the use of the post retrieval smoothing routine and gives the number of points to smooth over.
ENDO/EXO	The DV signals are normally divided by the endoatmospheric V to virtually eliminate aerosol effects (flag set to 1). This flag allows the DV to be divided instead by the exoatmospheric V (flag set to 2). The V retrievals are always divided by the exoatmospheric V so the flag for these channels is set to 0.
CAL/MEASURED V	This old option is no longer applicable
NUMBER OF FOV PASSES	This controls the number of times the onion peel process is repeated. As mentioned above in the section on calculation of simulated signal, the onion peel process is normally done 3 times. The T/P retrieval is hardwired in PTRET to do 3 passes.
LAYER START	The user can specify the tangent layer spacing and related items for each channel. The starting altitude can either be positive or negative. If the altitude is positive, the retrieval will start at this height. If the altitude is negative, the retrieval will check the signal to noise ratio, and start at an altitude where the signal is large enough to justify retrieving the species
NUMBER OF SEGMENTS	The user can specify several tangent layer schemes each with their own layer spacing. This input parameter instructs the software on how many of these schemes there are.
INDEX	Old non-applicable parameter. Set to 0.
Z START	For each of the tangent layer schemes, the top layer altitude is input.
Z STOP	For each of the tangent layer schemes the bottom layer altitude is specified. After all the tangent layers have been calculated, the inversion code checks the level 1 file for the good data flag that identifies the lowest altitude to process. The tangent layers are shifted downward to reach this lowest value effectively overriding the lowest layer specified by the user. Also, the software checks to make sure that no retrievals are attempted below where the FOV moves off the bottom edge of the sun.
THICKNESS	The layer spacing (thickness) for each of the tangent layer segments are required to construct the onion peel geometry between the top and bottom layer altitudes

TABLE 18-1 (Continued)
Descriptions of V19 control file parameters

SPECIES	CHAN. INDEX	FORWARD MODE	DIURNAL	FORWARD MODEL	AEROSOL OPTION	# INTERL	CONV TRAN	ATMOS SIGMA	MEAS SIGMA	MIX SPRED FUNCT	WGT DIS (KM)	SMOOTH	ENDO/EXO	CAL/MEAS	PASSES
T/P	1	0	0	1	1	1	0	1.0E-5	8.0E-4	1.0	1.5	0	0	0	1
H_2O	2	0	0	1	1	7	0	1.2E-6	8.0E-4	0.2	1.0	14	0	0	3
NO_2	3	0	1	1	1	7	0	1.0E-10	8.0E-4	0.2	0.8	14	0	0	3
O_3	4	0	1	1	1	7	0	1.0E-6	8.0E-4	0.2	0.8	15	0	0	3
NO DV	5	0	1	2	1	7	0	5.0E-4	6.0E-6	0.5	2.1	14	1	2	3
CH4 V	6	0	0	1	0	7	0	1.0E-4	1.0E-6	0.2	0.8	0	0	0	3
HCl V	7	0	0	1	0	1	0	2.5E-7	2.0E-4	1.0	0.8	14	0	0	3
CH_4 DV	8	0	1	2	1	1	0	1.0E-6	1.2E-5	0.2	2.1	0	1	2	3
HCl DV	9	0	1	2	1	1	0	2/6E-9	4.0E-6	0.2	2.1	0	1	2	3
HF DV	10	0	0	2	1	1	0	4.0E-9	8.0E-6	0.2	2.1	0	1	2	3
HF V	11	0	0	1	0	1	0	2.03-6	2.0E-4	1.0	0.8	0	0	2	3
NO AERO	12	0	1	1	-1	7	0	8.0E-4	8.0E-4	0.2	0.8	0	0	0	3
CH_4 AERO	13	0	1	1	0	7	0	8.0E-4	8.0E-4	0.2	0.8	0	0	0	3
HCL AERO	14	0	1	1	0	7	0	8.0E-4	8.0E-4	0.2	0.8	0	0	0	3
HF AERO	15	0	0	1	0	7	0	8.0E-4	8.0E-4	0.2	0.8	0	0	0	3
CO_2 AERO	16	0	0	1	0	7	0	8.0E-4	8.0E-4	0.2	0.8	0	0	0	3

TABLE 18-2
V19 control file parameters values
Channels/values shaded in gray not used in V19

Retrievals of a few parameters are not available with V19. For example, because of uncertainties in the interfering aerosol extinctions, the CH_4 retrievals using the CH_4 V and the HCl V signals were not attempted. Because of forward model concerns, such as CO_2 line mixing effects, the CO_2 channel aerosol retrieval was not carried out below the Z0 level for the P/T retrieval.

19 Output

The retrieval code produces two files that contain information concerning the retrievals. One file contains the retrieved temperature, mixing ratio, and aerosol extinction profiles; these retrievals are output on the altitude grid that was used for their retrieval. Only the aerosol retrievals are output on a standard grid. The second file contains the quality control information. It contains information on how to characterize the quality of the retrievals. Any problems that were encountered during the retrieval, such as reaching the maximum number of iterations when retrieving the mixing ratio profiles, are indicated by values in this file. Also, the precision estimates for the retrievals are in this file. These two files along with much of the Level 1 information are combined within the Level 2 processing routine CNDNS2D into the final Level 2 product. CNDNS2D also calculates some higher order aerosol products, and they are included in the Level 2 file. Because certain Level 1 data, such as signals, boresight positions, solar limb darkening curves, Doppler velocities, etc. are in the Level 2 file along with information about the retrievals themselves, it is easy to access this information to estimate their effects on the retrieved profiles. A complete description of the Level 2 file contents is given in Appendix 2.

20 Diagnostic Plotting Software

To help display the Level 2 data, a suite of plotting algorithms was developed called "Stoneware" (named after Ken Stone, who developed it). Based on IDL, it is capable of producing line plots of retrieved quantities versus pressure or altitude using the routines BPLOT or XY. Data can be plotted by event, by mode (rise or set), or all data for a day or for multiple days. Error bars can be plotted as well. Statistical comparisons can be generated by using PSTATS and PLOT STATS. Map displays can be created using, for example, 2DLAT. The data format used in the plotting was the "bsel" format created by the routine SEL. It was this package that created the plots for the HALOE Web site over much of the HALOE mission. These plot routines proved most useful in data validation.

21 Data Files in Runstream

The Level 2 runstream contains the many file names read in and written out during the Level 2 processing step that was run at the CDHF (Central Data Handling System) at NASA Goddard. The data system that controlled the handling of these files was known as UCSS (Upper Atmosphere Research

Satellite (UARS) Central Data Handling System (CDHF) Software System). The runsteam (examples archived) was written to use this system. A simulated version of this system was created for use at NASA Langley, where the HALOE code development occurred and where a parallel processing was run as an adjunct to the operational processing. In addition, toward the end of 2002 the CDHF was closed out and the processing was shifted to the HALOE Project at Langley. For each file there are attributes such as file ID and, of course, the file name. The UCSS software called in Level 2 dealt with the opening and closing of the files. An example of the files in the runstream is given in Appendix 4.

A few remaining details about the software are noted here. File names for Level 2 files do not have a calendar date in them. Instead, the files contain the UARS day number, according to UCSS protocol at the CDHF. The UARS day number is a counter that began with the launch of UARS. For example, July 18, 1992 is UARS day 311. One should also note that the data processed at the CDHF have a "_prod" tacked onto the end of the Level 2 file name. Data run at Langley on its VAX system have a "_rac" at the end of the file name. Toward the end of the mission, the ability was developed to reprocess certain "failed" days of data, in a so-called "event-by-event" fashion to avoid the entire day of data being lost due to the failure of one event. Those individual level 2 files (one for each event) were assembled/recombined into a single Level 2 file, and those files have the extension "_recombined". If the data were reprocessed for any reason, the data cycle number in the file name was increased (nominally to cycle 1).

22 Summary

HALOE has been a tremendous success because its design, construction, testing, and data analysis was meticulously planned and executed. The algorithms used in the data processing were refined and improved constantly throughout its long mission life. This report represents a detailed overview of the Level 2 software used to retrieve the many archived data products. The purpose of this report is two-fold: (1) to show the care that was taken in every step of the level 2 processing to assure accurate products, and (2) to describe the algorithms in some detail to facilitate comparisons with measurements by other experimenters.

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Appendices

Appendix 1: V19 Level 1 File Description

A HALOE Level 1 file is organized into blocks of data for each event and follows to some extent the Standard Formatted Data Units (SFDU) data format. The data for the events are arranged chronologically in time over the course of a single day. The data for each event block is organized in turn into three sections: the track, the solar scan, and the calibration wheel data. Each section has its own header. The following is an example of this structure for three events:

Track data for event 1
Solar Scan data for event 1
Calibration wheel data for event 1
Track data for event 2
Solar Scan data for event 2
Calibration wheel data for event 2
Track data for event 3
Solar Scan data for event 3
Calibration wheel data for event 3

A few things should be pointed out. Comparing a level 1 file to a Level 2 file one sees that unlike the Level 2 file, there is no file header for the Level 1 file. Also, although the calibration wheel was not used from between1994 and the fall of 2006, calibration wheel records have always been included even if they contain no data.

These files are written in unformatted, sequential FORTRAN records. This method of writing data is highly dependent upon the computer platform and operating system used, possibly even the compiler as well. For example, a FORTRAN program on a VAX/VMS computer has one way of writing out this type of record, while a Unix platform it would be another scheme. The byte ordering of the machine may also need to be taken into account. Generally when a FORTRAN program writes unformatted, sequential records, it places tags and the beginning and, depending upon the platform, possibly at the end of a record. This presents a bit of a coding challenge for reading the data using another computer language such as C, C++, or Java.

The header records for the track, solar scan, and calibration wheel data are very similar. There are some differences in the entries in their arrays of summary data.

1. Track Data

This section contains data while HALOE was viewing the sun as it either rose or set through the earth’s atmosphere. The data are organized into a header that contains identification and an array of summary information. This array is presented in a separate table. After the header are the track records.

Track Header

VARIABLE	NAME	CONTENTS
1	LABEL	CHARACTER*10 label showing type of header LABEL = 'STD_L1_TK '
2	NHEAD	Size of header array. (INTEGER*4) Currently NHEAD = 120.
3	NHDLEV	The generation of the file. (INTEGER*4) Signifies when a change has been made to the structure of the file. Currently NHDLEV = 8
4	HDTYP	Header type (INTEGER*4). HDTYP = 11 for Track
5	Header Array	120 element array of summary data for event. See next table. Unless noted otherwise, values are REAL*4 and single precision

Contents of Track Header Array. All parameters REAL*4 unless otherwise noted.

POSITION IN HEADER ARRAY	NAME	CONTENTS
1	DATES	date for start of track data (UDTF) (INTEGER*4) This is year and day of year. The year is expressed as year minus 1900.
2	TIMES	time for start of track data (UDTF) (INTEGER*4) This is milliseconds since midnight
3	DATEE	date for end of track data (UDTF) (INTEGER*4)
4	TIMEE	time for end of track data (UDTF) (INTEGER*4) This is milliseconds since midnight. If the event crosses into the next day, then the time will be from the start of that day.
5	MODE	track mode indicator (8=SET, 10=RISE) (INTEGER*4)

POSITION IN HEADER ARRAY	NAME	CONTENTS
6	NEVENT	event number (INTEGER*4)
7	SANG	apparent zenith angle for 1st data point (radians)
8	AINC	angle increment between points data points (radians)
9	SZ	apparent tangent altitude for 1st point (km)
10	ZINC	apparent tangent altitude increment (km)
11	NPTS	number of data points (INTEGER*4)
12	NRCRDS	not applicable for LEVEL 1 headers.
13	IORB	UARS orbit number (INTEGER*4)
14	SALT	spacecraft altitude (km) at TIMES
15	SLAT	spacecraft latitude (degrees) at TIMES
16	SLON	spacecraft longitude (degrees) at TIMES
17-28	NERROR(12)	Total number of error occurrences for each channel detected by the unpacking routine UNPACKO. The channel order is the same as in the signal array. (INTEGER*4)
29-40	EXOSIG(12)	exoatmospheric signals for each channel (Volts). The channel order is the same as in the signal array.
41-52	SIGVAL(12)	1σ value (arcminutes) for Gaussian apodization function for each channel. The channel order is the same as in the signal array.
53	ERAD90	earth radius (km) for subtangent point of 90 km tangent altitude ray
54	ERAD30	earth radius (km) for subtangent point of 30 km tangent altitude ray
55	ERAD6	earth radius (km) for subtangent point of 6 km tangent altitude ray
56	DCO2T	average detector housing temperatures (K) for CO_2
57	DH_2OT	average detector housing temperatures (K) for H_2O
58	DNO_2T	average detector housing temperatures (K) for NO_2
59	DO_3T	average detector housing temperatures (K) for O_3
60	$SDCO_2T$	standard deviation of detector housing temperature (K) for CO_2

POSITION IN HEADER ARRAY	**NAME**	**CONTENTS**
61	DH_2OT	standard deviation of detector housing temperature (K) for H_2O
62	DNO_2T	standard deviation of detector housing temperature (K) for NO_2
93	DO_3T	standard deviation of detector housing temperature (K) for O_3
64	CH_4FLT	average spectral filter temperature (K) for CH_4
65	HCLFLT	average spectral filter temperature (K) for HCl
66	NOFLT	average spectral filter temperature (K) for NO
67	HFFLT	average spectral filter temperature (K) for HF
68	SCH4FLT	standard deviation of spectral filter temperature (K)
69	SHCLFLT	standard deviation of spectral filter temperature (K)
70	SNOFLT	standard deviation of spectral filter temperature (K)
71	SHFFLT	standard deviation of spectral filter temperature (K)
72	GCTCH4	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
73	GCTHCL	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
74	GCTNO	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
75	GCTHF	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
76	SGCT CH4	standard deviation of cell temperature indicators (K)
77	SGCTHCL	standard deviation of cell temperature indicators (K)
78	SGCTNO	standard deviation of cell temperature indicators (K)
79	SGCTHF	standard deviation of cell temperature indicators (K)
80	BETA	beta angle (deg)
81-90	Spares	
91	MSIS FLAG	Indicates if MSIS model was used to determine high altitude Temperature profile (INTEGER*4) 1 = MSIS model used for temperature determination 0 = MSIS model not used.

POSITION IN HEADER ARRAY	NAME	CONTENTS
92	Spare	
93	Spare	
94	ALT_GAIN	The apparent altitude where the fine sun sensor on the instrument changes its Gain value (km)
95-97	Spares	
98	PTFLAG	defines data used to generate pressure registration (INTEGER*4) = 0 if NMC data used = 1 if UKMO data used
99-120	Spares	

Track Section's Data Records. All parameters REAL*4 unless otherwise noted. NPTS is 491.

RECORD	CONTENTS	VALUES
1	Track Header.	See table above
2	apparent zenith angles (radians). These angular measurements are defined from local zenith down to each FOV angular position.	NPTS
3	apparent tangent altitudes (km)	NPTS
4	pressures (mb) at apparent tangent altitudes This is NMC data if PTFLAG = 0 This is UKMO data if PTFLAG = 1	NPTS
5	temperatures (K) at apparent tangent altitudes This is NMC data if PTFLAG = 0 This is UKMO data if PTFLAG = 1	NPTS
6	apparent tangent latitudes (degrees)	NPTS
7	apparent tangent longitudes (degrees)	NPTS
8	elapsed time (sec) from start of mode	NPTS
9	velocities (km/sec along line-of-sight) for the sun relative to the spacecraft. Defined as separation velocity : increasing separation is positive.	NPTS

RECORD	CONTENTS	VALUES
10	velocities (km/sec along line-of-sight) for the atmosphere relative to the spacecraft. Defined as separation velocity : increasing separation is positive.	NPTS
11	fss position (radians from top edge)	NPTS
12	(SMTON(J)=1,12), (SMTF(J)=1,12),(SMTP(J)=1,12) SMTON(J)=1 if channel J is filtered SMTF(J)=noise reduction factor for channel J SMTP(J)=noise/signal desired for channel J Channel order: CO_2, H_2O, NO_2, O_3, CH_4, CH_4D, HCL, HCLD, NO, NOD, HF, HFD	(INTEGER*4) (INTEGER*4) (REAL*4)
13	IFILT(1), INTCO2(J),J=1,NPTS, LINTCO2 (J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTCO2=Intensity (signal) in volts LINTCO2= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
14	IFILT(2), INTH2O (J),J=1,NPTS, LINTH2O(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTH2O=Intensity (signal) in volts LINTH2O= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
15	IFILT(3), INTNO2(J),J=1,NPTS, LINTNO2(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTNO2=Intensity (signal) in volts LINTNO2= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
16	IFILT(4), INTO3(J),J=1,NPTS, LINTO3 (J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTO3=Intensity (signal) in volts LINTO3= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4

RECORD	CONTENTS	VALUES
17	IFILT(5), INTCH4(J),J=1,NPTS, LINT CH4(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTCH4=Intensity (signal) in volts LINTCH4= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
18	IFILT(6), INT CH4D(J),J=1,NPTS, LINTCH4D(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTCH4D=Intensity (signal) in volts LINTCH4D= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
19	IFILT(7), INTHCL(J),J=1,NPTS, LINTHCL(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTHCL=Intensity (signal) in volts LINTHCL= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
20	IFILT(8), INTHCLD(J),J=1,NPTS, LINTHCLD(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTHCLD=Intensity (signal) in volts LINTHCLD= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
21	IFILT(9), INTNO(J),J=1,NPTS, LINTNO(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTNO=Intensity (signal) in volts LINTNO= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
22	IFILT(10), INTNOD(J),J=1,NPTS, LINTNOD(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTNOD=Intensity (signal) in volts LINTNOD= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
23	IFILT(11), INTHF(J),J=1,NPTS, LINTHF(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTHF=Intensity (signal) in volts LINTHF= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4

RECORD	CONTENTS	VALUES
24	IFILT(12), INTHFD(J),J=1,NPTS, LINTHFD(J),J=1,NPTS IFILT=1 if smoothed, 0 if no smoothing, INTHFD=Intensity (signal) in volts LINTHFD= Lockdown angle from top edge of sun in radians	(INTEGER*4) (REAL*4) (REAL*4
25	NC, COMMENT(I),I=1,NC NC number of comments describing the file COMMENT(NC) comments describing the file	(INTEGER*4) (CHARACTER*80)
26	pressures (mb) at apparent tangent altitudes This is UKMO data if PTFLAG = 0 This is NMC data if PTFLAG = 1	NPTS
27	temperatures (K) at apparent tangent altitudes This is UKMO data if PTFLAG = 0 This is NMC data if PTFLAG = 1	NPTS
28	Off-Sun offset (volts) REAL*4 in order below CO_2, H_2O, NO_2, O_3, CH_4, DCH_4, HCL, DHCL, NO, DNO, HF, & DHF	12
29	This is an INTEGER*4 value (NUMREC). Number of records between this record and the end of scan header	1
30	ALTLOW, ALTHIGH, BOTEXC, SOLEXTLO, APPTOPLO ALTLOW = Low range of valid data (km) ALTHIGH = High range of valid data (km) BOTEXC = Number of diodes exceeded when track was lost SOLEXTLO = solar extent at ALTLOW (arcmin) APPTOPLO = altitude of apparent top edge at ALTLOW (km)	5
31	gimble elevations angles (radians)	NPTS
32	gimble zenith angles (radians)	NPTS
33	apparent solar extent (radians)	NPTS
34	apparent altitude of solar top edge (km)	NPTS
35	refraction angles (at $1000 cm^{-1}$) (radians)	NPTS
36	Spacecraft latitudes (degrees)	NPTS
37	Spacecraft longitudes (degrees)	NPTS
38	Spacecraft altitudes (km)	NPTS

RECORD	CONTENTS	VALUES
39	Instrument VPEAK (Volts)	NPTS
40	Boresight correction using VPEAK (Volts)	NPTS
41	Zenith Correction	1
42	Zenith Difference	1
43	Yaw (not in later data due to loss of UARS earth limb sensor)	1
44	Pitch (not in later data due to loss of UARS earth limb sensor)	1
45	Roll (not in later data due to loss of UARS earth limb sensor)	1
46	Drift Corrections for CO_2 channel	NPTS
47	Drift Corrections for H_2O channel	NPTS
48	Drift Corrections for NO_2 channel	NPTS
49	Drift Corrections for O_3 channel	NPTS
50	Drift Corrections for CH_4 V channel	NPTS
51	Drift Corrections for CH_4 dV channel	NPTS
52	Drift Corrections for HCl V channel	NPTS
53	Drift Corrections for HCl dV channel	NPTS
54	Drift Corrections for NO V channel	NPTS
55	Drift Corrections for NO dV channel	NPTS
56	Drift Corrections for HF V channel	NPTS
57	Drift Corrections for HF dV channel	NPTS
58	Mismatch Correction for CH_4 dV channel	NPTS
59	Mismatch Scale Factor for CH_4 dV channel	1
60	Mismatch Correction for HCl dV channel	NPTS
61	Mismatch Scale Factor for HCl dV channel	1
62	Mismatch Correction for NO dV channel	NPTS
63	Mismatch Scale Factor for NO dV channel	1
64	Mismatch Correction for HF dV channel	NPTS
65	Mismatch Scale Factor for HF dV channel	1

RECORD	CONTENTS	VALUES
66	Source Function for CO_2 channel. This parameter is the convolution of the channel's FOV over the solar limb darkening curve. It was included to help create transmissions from the signals; it is essentially the same as the refraction functions in the Level 2 files.	NPTS
67	Source Function for H_2O channel	NPTS
68	Source Function for NO_2 channel	NPTS
69	Source Function for O_3 channel	NPTS
70	Source Function for CH_4 V channel	NPTS
71	Source Function for CH_4 dV channel	NPTS
72	Source Function for HCl V channel	NPTS
73	Source Function for HCl dV channel	NPTS
74	Source Function for NO V channel	NPTS
75	Source Function for NO dV channel	NPTS
76	Source Function for HF V channel	NPTS
77	Source Function for HF dV channel	NPTS
78	CSS Azimuth	1

2. Solar Scan Data

These measurements were taken before or after the occultation, depending upon whether the event was, respectively, a sunset or a sunrise. During these times HALOE was viewing the Sun above the Earth's atmosphere. The HALOE telescope would scan across the Sun 9 times in elevation from one end to the other. These data are processed in Level 1 into a single solar limb darkening curves (SLDC's) for each channel. Although it has much of the same data as the header array for track, there are several elements in the solar scan array header that are empty since these fields do not apply to solar scans. The values in the mode element are the "xtask" telemetry values for acquiring solar scan data during sunrises and sunsets. They are, respectively, 3 for sunset and 15 for sunrise.

Solar Scan Header

VARIABLE	NAME	CONTENTS
1	LABEL	CHARACTER*10 label showing type of header LABEL = 'STD_L1_SM '
2	NHEAD	Size of header array. Currently NHEAD = 120.
3	NHDLEV	The generation of the file. (INTEGER*4) Signifies when a change has been made to the structure of the file. Currently equal to 6.
4	HDTYP	Header type (INTEGER*4). HDTYP = 12 for Solar Scan
5	Header Array	120 element array of summary data for event. See next table. Unless noted otherwise, values are REAL *4 and single precision.

Contents of Solar Scan Header Array. All parameters REAL *4 unless otherwise noted.

POSITION IN HEADER ARRAY	NAME	CONTENTS
1	DATES	date for start of solar scan data (UDTF) INTEGER*4
2	TIMES	time for start of solar scan data (UDTF) (INTEGER*4)
3	DATEE	date for end of solar scan data (UDTF) (INTEGER*4)
4	TIMEE	time for end of solar data (UDTF) (INTEGER*4)
5	MODE	Solar scan mode indicator (3=SET, 15=RISE) (INTEGER*4)
6	NEVENT	event number (INTEGER*4)
7	SANG	apparent zenith angle for 1st data point (radians) relative to top edge of sun.
8	AINC	angle increment between points data points (radians)
9	SZ	apparent tangent altitude for 1st point (km)
10	ZINC	apparent tangent altitude increment (km).
11	NPTS	number of solar scan points (INTEGER*4)
12	NRCRDS	not applicable for LEVEL 1 headers.
13	IORB	UARS orbit number (INTEGER*4)
14	SALT	spacecraft altitude (km) at TIMES
15	SLAT	spacecraft latitude (degrees) at TIMES
16	SLON	spacecraft longitude (degrees) at TIMES
17-55	Spares	
56	DCO2T	average detector housing temperatures (K) for CO_2
57	DH_2OT	average detector housing temperatures (K) for H_2O
58	DNO_2T	average detector housing temperatures (K) for NO_2
59	DO_3T	average detector housing temperatures (K) for O_3
60	$SDCO_2T$	standard deviation of detector housing temperature (K) for CO_2
61	DH_2OT	standard deviation of detector housing temperature (K) for H_2O

POSITION IN HEADER ARRAY	**NAME**	**CONTENTS**
62	DNO_2T	standard deviation of detector housing temperature (K) for NO_2
93	DO_3T	standard deviation of detector housing temperature (K) for O_3
64	CH_4FLT	average spectral filter temperature (K) for CH_4
65	HCLFLT	average spectral filter temperature (K) for HCl
66	NOFLT	average spectral filter temperature (K) for NO
67	HFFLT	average spectral filter temperature (K) for HF
68	SCH_4FLT	standard deviation of spectral filter temperature (K)
69	SHCLFLT	standard deviation of spectral filter temperature (K)
70	SNOFLT	standard deviation of spectral filter temperature (K)
71	SHFFLT	standard deviation of spectral filter temperature (K)
72	GCTCH4	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
73	GCTHCL	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
74	GCTNO	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
75	GCTHF	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
76	SGCT CH4	standard deviation of cell temperature indicators (K)
77	SGCTHCL	standard deviation of cell temperature indicators (K)
78	SGCTNO	standard deviation of cell temperature indicators (K)
79	SGCTHF	standard deviation of cell temperature indicators (K)
80 -120	Spares	

Solar Scan Section's Data Records

RECORD	CONTENTS	VALUES
1	Solar Scan Header (LABEL ='STD_L1_SM' HDTYP = 12) LABEL, NHEAD, NHDLEV, HDTYP, (HEAD(I),I=1, NHEAD)	
2	CO_2 V Solar scan data (see below)	REAL*4
3	H_2O V Solar scan data	REAL*4
4	NO_2 V Solar scan data	REAL*4
5	O_3 V Solar scan data	REAL*4
6	CH_4 V Solar scan data	REAL*4
7	HCl V Solar scan data	REAL*4
8	NO V Solar scan data	REAL*4
9	HF V Solar scan data	REAL*4
10	CH_4 DV Solar scan data	REAL*4
11	HCL DV Solar scan data	REAL*4
12	NO DV Solar scan data	REAL*4
13	HF DV Solar scan data	REAL*4

NOTE: In the above solar scan data that follows the header, each record of Solar Scan Data (records 2-13) for a given channel has the following data structure. All values are REAL*4. NPTS is 200.

LD (NPTS)	The unconvolved (HALOE FOV removed) measured solar limb-darkening curve for the channel normalized to the peak value. The edges of these curves have the Allen (theoretical curves) spliced on because the deconvolution process causes severe ringing at the sharp solar edge; the edges are replaced by the edges of the Allen (channel dependent) curves. These are the solar source functions used in the Level 2 processing.
DLD (NPTS)	Difference between the measured HALOE solar limb darkening curve and the LD solar limb-darkening curve convolved with the HALOE FOV.
ELD	RMS difference of DLD.
EMLD	EMLD, Maximum value of DLD

SPOT (NPTS)	Sun spot indicator. Absolute value of the difference between the measured HALOE solar limb darkening curve and the theoretically/empirically derived solar limb-darkening curve (Allen) convolved with the HALOE FOV. This array is then divided by the normalized noise value for that channel which converts this difference to N. Where difference = N*(channel noise). This indicator may not be reliable.

3. Calibration Wheel Data

The procedure for this measurement was to rotate the calibration wheel through its 12 positions while HALOE was observing the Sun above the Earth's atmosphere. The apertures of the calibration wheel contained neutral density filters of various strengths as well as gas cells. When this test was not being run, the calibration wheel was set to the clear aperture, which is free of any optical element. These measurements were stopped some time during 1994, due to a concern that the calibration wheel might fail in a way that would obstruct HALOE's optical view path. Calibration wheel measurements were taken once again for a few days during the fall of 2005 near the end of the mission. The data were useful in a study of the nonlinearity of HALOE's detectors, and the chance of losing the last few days' data was considered to be worth the risk (and the calibration wheel performed without a problem!).

The data contained in the Calibration data section of the Level 1 files is probably not written out correctly. All recent (2005-2008) studies using the calibration wheel data have been performed using Level 0 data available at the Goddard DAAC. Therefore, the DAAC should be used as the source of this data. In order to understand the data contained in the Level 0 files, it is necessary to use both the HALOE Flight Operations HALOE Telemetry Compendium and the UARS CDHF Software System (UCSS) Programmers Guide to Production Software Support Services. It is planned that a copy of the data along with data description and data readers will be retained along with the other information contained in the HALOE documentation archive. For the sake of completeness, the Level 1 calibration data contents are included in the following tables. This should facilitate the data user's ability to read past this data and on to the next event.

The description of what should have been written out in this data section states that the data contained in the header array depends upon whether there is calibration wheel data. For the events with calibration data, this array was planned to have much of the same data as the one for the solar scans. For the events that do not have this data, only the mode element and another element would contain data. Although the data records are always present for the calibration wheel, they should be filled with zeros if no data is present. The values in the mode element are the xtask telemetry values for acquiring solar scan data during sunrises and sunsets. They are, respectively, 5 for sunset and 12 for sunrise.

Calibration Wheel Header

POSITION	NAME	CONTENTS
1	LABEL	CHARACTER*10 label showing type of header LABEL = 'STD_L1_CM '
2	NHEAD	Size of header array. Currently NHEAD = 120.
3	NHDLEV	The generation of the file. (INTEGER*4) Signifies when a change has been made to the structure of the file. Currently equal to 6.
4	HDTYP	Header type (INTEGER*4). HDTYP = 13
5	Header Array	120 element array of summary data for event. See table below.

Contents of Calibration Wheel Header Array.

POSITION IN HEADER ARRAY	NAME	CONTENTS
1	DATES	date for start of calibration wheel data (UDTF) INTEGER*4
2	TIMES	time for start of calibration wheel data (UDTF) (INTEGER*4)
3	DATEE	date for end of calibration wheel data (UDTF) (INTEGER*4)
4	TIMEE	time for end of calibration wheel data (UDTF) (INTEGER*4)
5	MODE	Calibration wheel mode indicator (5=SET, 12=RISE) (INTEGER*4)
6	NEVENT	event number (INTEGER*4)
7-11	Spares	
12	NRCRDS	not applicable for LEVEL 1 headers.

POSITION IN HEADER ARRAY	NAME	CONTENTS
13	IORB	UARS orbit number (INTEGER*4)
14	SALT	spacecraft altitude (km) at TIMES
15	SLAT	spacecraft latitude (degrees) at TIMES
16	SLON	spacecraft longitude (degrees) at TIMES
17-55	Spares	
56	DCO2T	average detector housing temperatures (K) for CO_2
57	DH_2OT	average detector housing temperatures (K) for H_2O
58	DNO_2T	average detector housing temperatures (K) for NO_2
59	DO_3T	average detector housing temperatures (K) for O_3
60	$SDCO_2T$	standard deviation of detector housing temperature (K) for CO_2
61	DH_2OT	standard deviation of detector housing temperature (K) for H_2O
62	DNO_2T	standard deviation of detector housing temperature (K) for NO_2
93	DO_3T	standard deviation of detector housing temperature (K) for O_3
64	CH_4FLT	average spectral filter temperature (K) for CH_4
65	HCLFLT	average spectral filter temperature (K) for HCl
66	NOFLT	average spectral filter temperature (K) for NO
67	HFFLT	average spectral filter temperature (K) for HF
68	SCH4FLT	standard deviation of spectral filter temperature (K)
69	SHCLFLT	standard deviation of spectral filter temperature (K)
70	SNOFLT	standard deviation of spectral filter temperature (K)
71	SHFFLT	standard deviation of spectral filter temperature (K)
72	GCTCH4	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
73	GCTHCL	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
74	GCTNO	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT

POSITION IN HEADER ARRAY	NAME	CONTENTS
75	GCTHF	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT
76	SGCT CH4	standard deviation of cell temperature indicators (K)
77	SGCTHCL	standard deviation of cell temperature indicators (K)
78	SGCTNO	standard deviation of cell temperature indicators (K)
79	SGCTHF	standard deviation of cell temperature indicators (K)
80 -120	Spares	

Calibration Wheel Section's Data Records

RECORD	CONTENTS	VALUES
1	Calibration Wheel header	See table above
2	calibration wheel intensities (volts) for: CO_2, H_2O, NO_2, O_3, CH_4, DCH_4, HCl, DHCl, NO, DNO, HF, & DHF for cal wheel positions 0-11	144 entries, one for each channel and wheel position.
3	calibration wheel intensity standard deviations (volts) for: CO_2, H_2O, NO_2, O_3, CH_4, DCH_4, HCl, DHCl, NO, DNO, HF, & DHF for cal wheel positions 0-11	144 entries, one for each channel and wheel position.

Appendix 2: V19 Level 2 File Description

HALOE Level 2 Format/Contents for Version 19

HALOE Level 2 files contain the data for one day and to some extent follow the Standard Formatted Data Units (SFDU) format. The standards for this data format required certain information be included such as number of records and other helpful information. The Level 2 files are labeled according to UARS day number and are organized into two blocks of data for each event with a standard file header at the beginning of the file. The following is an example of this structure for three events:

SFDU header and daily summary
Header for event 1
Data products and useful level 1 data for event 1
Header for event 2
Data products and useful level 1 data for event 2
Header for event 3
Data products and useful level 1 data for event 3

The first record in the file header contains a Standard Formatted Data Units (SFDU) header. Additional records in the file header contain a summary of a few parameters for the day's data. The data for each event block contains a header and then the associated data. These events are arranged chronologically in time over the course of a single day. The data is composed of some Level 1 data, the Level 2 retrieval products and some aerosol products created by the routine CNDNS2D that reads in the Level 1 file and the Level 2 products to create the final level 2 file.

The top of the Level 2 data file has the following SFDU header and daily summary.

RECORD	CONTENTS
1	SFDU Header CHARACTER*72 "CCSD1Z000001000000052CCSD1R00000300000032DELIMITER =EOF;TYPY=NURS1I00HA02;"
2	CHFH, NWORDS, NHDLEV2, NHEAD CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 NHDLEV2 Level 2 file generation number INTEGER*4 NHEAD Number of values in the level 2 header INTEGER*4

RECORD	CONTENTS
3	CHFH, NCOM, (COMMENT(I),I=1,NCOM) CHFH CHARACTER*10, Character descriptor of this record NCOM Number of comments that follow INTEGER*4 COMMENT Comments describing the file CHARACTER*80
4	CHFH, NWORDS, UARS_DAY, NL1EVNTS, NRET, NSKIPPED CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 UARS_DAY UARS Day INTEGER*4 NL1EVENTS Number of events in the level 1 file INTEGER*4 NRET Number of events retrieved. INTEGER*4 NSKIP Number of events skipped INTEGER*4
5	CHFH, NWORDS, (NSKIPPED(I),I=1,NWORDS) CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 NSKIPPED Array of skipped events INTEGER*4 For example: NSKIPPED(2)=0 Means event #2 was processed NSKIPPED(2)=2 Means event #2 was skipped
6	CHFH, NWORDS, AVGLAT_SS, AVGVELS_SS, AVGVELA_SS CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 AVGLAT_SS Average 30 km Tangent Point Altitude (TPA) latitude for SS events (deg) REAL*4 AVGVELS_SS Average 30 km TPA S/C velocity relative to the sun for SS events (km/sec) REAL*4 AVGVELS_SS Average 30 km TPA S/C velocity relative to the atmosphere for SS events (km/sec) REAL*4
7	CHFH, NWORDS, AVGLAT_SR, AVGVELS_SR, AVGVELA_SR CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 AVGLAT_SR Average 30 km Tangent Point Altitude (TPA) latitude for SS events (deg) REAL*4 AVGVELS_SR Average 30 km TPA S/C velocity relative to the sun for SR events (km/sec) REAL*4 AVGVELS_SR Average 30 km TPA S/C velocity relative to the atmosphere for SR events (km/sec) REAL*4
8	CHFH, NWORDS, (EVNT_TYPE(I),I=1,NWORDS) CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 EVNT_TYPE Event type of each event used for summary data CHARACTER*10

RECORD	CONTENTS
9	CHFH, NWORDS, (SUM_LAT(I), I=1,NWORDS) CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 SUM_LAT 30 km Tangent Point Altitude (TPA) latitudes for each summary event (degrees) REAL*4
10	CHFH, NWORDS, (SUM_LON(I), I=1,NWORDS) CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 SUM_LON 30 km Tangent Point Altitude (TPA) longitudes for each summary event (degrees) REAL*4
11	CHFH, NWORDS, (SUM_VELS(I), I=1,NWORDS) CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 SUM_VELS 30 km Tangent Point Altitude (TPA) S/C velocity relative to the sun for each summary event (km/sec) REAL*4
12	CHFH, NWORDS, (SUM_VELA(I),I=1,NWORDS) CHFH CHARACTER*10, Character descriptor of this record NWORDS Number of elements that follow INTEGER*4 SUM_VELA 30 km Tangent Point Altitude (TPA) S/C velocity relative to the atmosphere for each summary event (km/sec) REAL*4
13	CHFH, NWORDS CHFH CHARACTER*10, Last record NWORDS Number of elements that follow INTEGER*4

For each event, there is a header and then the data. The event header is as follows.

POSITION	NAME	CONTENTS
1	LABEL	CHARACTER*10 label showing type of header See HDTYP below
2	NHEAD	Size in REAL*4 words for this header (INTEGER*4) Currently 127 for Level 2 (NHDLEV = 19)
3	NHDLEV	The generation of the file. (INTEGER*4) Changes in the structure of the file will cause a change in this number. Currently NHDLEV = 19 for Level 2

POSITION	NAME	CONTENTS
4	HDTYP	Header type (INTEGER*4). 2 = LEVEL 2 standard 'STD_L2 ' Level 2
5	HEAD (NHEAD)	127 element event header. Unless otherwise noted all data is real *4. See table below for event header contents.

Contents of Header Array. All parameters REAL*4 unless otherwise noted.

POSITION IN HEAD	NAME	CONTENTS
1	DATES	date for start of track data (UDTF) INTEGER*4 This is year and day of year. The year is expressed as year minus 1900
2	TIMES	time for start of track data (UDTF) INTEGER*4 This is milliseconds since midnight.
3	DATEE	date for end of track data (UDTF) INTEGER*4 This is year and day of year. The year is expressed as year minus 1900
4	TIMEE	time for end of track data (UDTF) INTEGER*4 This is milliseconds since midnight. If the event crosses into the next day, then the time will be from the start of that day.
5	MODE	track mode indicator (8=SET, 10=RISE) INTEGER*4
6	NEVENT	event number (-1 for average events – not done in V19) INTEGER*4
7	SANG	apparent zenith angle for 1st data point (radians)
8	AINC	angle increment between points data points (radians)
9	SZ	apparent tangent altitude for 1st point (km)
10	ZINC	apparent tangent altitude increment (km)
11	NPTS	number of data samples INTEGER*4
12	NRCRDS	number of records INTEGER*4
13	IORB	UARS orbit number INTEGER*4
14	SALT	spacecraft altitude (km) at TIMES

POSITION IN HEAD	**NAME**	**CONTENTS**
15	SLAT	spacecraft latitude (degrees) at TIMES
16	SLON	spacecraft longitude (degrees) at TIMES
17-28	NERROR(12)	Total number of error occurrences for each channel detected by the unpacking routine UNPACKO. The channel order is the same as in the signal array. INTEGER*4
29-40	EXOSIG(12)	exoatmospheric signals for each channel (Volts). The channel order is the same as in the signal array.
41-52	SIGVAL(12)	1σ value (arcminutes) for Gaussian apodization function for each channel. The channel order is the same as in the signal array.
53	ERAD90	earth radius (km) for subtangent point of 90 km tangent altitude ray
54	ERAD30	earth radius (km) for subtangent point of 30 km tangent altitude ray
55	ERAD6	earth radius (km) for subtangent point of 6 km tangent altitude ray
56-59	DxxxT	average detector housing temperatures (K) for: CO_2, H_2O, NO_2, & O_3
60-63	SDxxxT(4)	standard deviation of detector housing temperatures (K)
64-67	xxxFLT(4)	average spectral filter temperatures (K) for: CH_4, HCl, NO, & HF
68-71	SxxxFLT(4)	standard deviation of spectral filter temperatures (K)
72-75	GCTxxx(4)	average gas cell temperature indicators (K): MFMT, MFCAT, GCRT, & HFGCT (CH_4, HCl, NO, HF)
76-79	SGCTxxx(4)	standard deviation of cell temperature indicators (K)
80	BETA	beta angle (deg)
81	STLAT	latitude (degrees) for 150 km subtangent point
82	STLON	longitude (degrees) for 150 km subtangent point
83	ETLAT	latitude (degrees) for 3 km subtangent point
84	ETLON	longitude (degrees) for 3 km subtangent point
85	EVNLAT	latitude (degrees) for 30 km subtangent point

POSITION IN HEAD	NAME	CONTENTS
86	EVNLON	longitude (degrees) for 30 km subtangent point
87	EVNVELS	S/C velocity relative to the sun for the 30 km tangent ray (km/sec)
88	EVNVELA	S/C velocity relative to the atmosphere for the 30 km tangent ray (km/sec)
89-90	METH(4)	endo/exo atmospheric and measure/calculated V code for the gas filter channels: NO, CH_4 (CH_4 DV), HCl, & HF INTEGER*2
91	MSISFLAG	Indicates if MSIS model was used to determine high altitude Temperature profile INTEGER*4 1 = MSIS model used for temperature determination 0 = MSIS model not used.
92	CH4_SAT_Z	The altitude where the CH_4DV channel saturates (km) REAL*4
93	CH4_SAT_P	The pressure at the altitude where the CH_4DV channel saturates (mb)
94	ALT_GAIN	The apparent where the fine sun sensor on the instrument changes its Gain value (km)
95	Z_CIRRUS	Altitude of cirrus tops, if detected (km)
96	MCH4	CH_4 merged technique INTEGER*4 There was only one technique used for merging the retrieved CH_4 and climatological CH_4 profile; the merged profile extended from 3.0 to 150km for use as an interferent.
97	EVNSTAT	status flag for this event INTEGER*4 0 = skipped event i.e. level 1 data only 1 = level 1 data and level 2 data
98	PTFLAG	defines data used to generate pressure registration INTEGER*4 = 0 if NMC data used = 1 if UKMO data used
99-104	SMOOTH(12)	index for vertical smoothing (INTEGER*2)
105-110	INDAERO(12)	index for aerosol model (INTEGER*2)
111	ALTLOW	lower range of valid data (km)
112	ALTHIGH	high range of valid data (km)
113	BOTEXC	number of diodes exceeded when track was lost
114	SOLEXTLO	solar extent at ALTLOW (arcmin)

POSITION IN HEAD	NAME	CONTENTS
115	APPTOPLO	altitude of the apparent top edge of the sun at ALTLOW
116	ZA_OFF_SUN	altitude at which FOV starts to slide off bottom of the sun (km)
117	ZTROP	Tropopause altitude (km)
118	PTROP	pressure at ZTROP (mb)
119	TTROP	temperature at ZTROP (K)
120-127	IDIFLAG(16)	NOx and O_3 diurnal gradient indicator for each channel: CO_2, H_2O, NO_2, O_3, NO, CH_4 DV, CH_4 (HCl V), CH_4 V, HCl, HF HFV NOAERO CH_4AERO HClAERO HFAERO INTEGER*2

The data are next and have the form

2 to NRCRDS+1	CHAR_LABEL, INDEX, NUM, (ARRAY(I), I=1,NUM) where CHAR_LABEL: Data array descriptor (CHARACTER*10) INDEX: Unique index for this data array (INTEGER*4) NUM: Number of elements that follow (INTEGER*4) ARRAY(NUM): Data values (REAL*4 except for the records with SMTON, SMTF, and IFILT, which are INTEGER*4 instead) See following table for complete description.

The data in records 2 to NRCRDS+1 are listed below. NOTE: To access the data, you must read in all NRCRDS records and then use the INDEX number to reference the desired data. If NUM=0, then no data exists in the array. The labels are all 10 characters long. All parameters are REAL*4 unless otherwise noted. If any parameter is not available in V19, the label has a N/A.

INDEX	CONTENTS	LABEL
1	apparent tangent altitudes (km)	'APPTANALT'
9	apparent tangent altitude pressures from NMC (mb) NOTE: this is UKMO data if PTFLAG =1	'PRAPPTNZ'
10	apparent tangent altitude temperatures from NMC (K)	'TEMAPPTNZ'

INDEX	CONTENTS	LABEL
	NOTE: this is UKMO data if PTFLAG =1	
3	apparent subtangent point latitudes (deg)	'APPTANLAT'
4	apparent subtangent point longitudes (deg)	'APPTANLON'
126	UKMO pressures for each apparent altitude (mb) NOTE: this NMC data if PTFLAG =1	'UKMOPR'
127	UKMO temperatures for each apparent altitude (K) NOTE: this is NMC data if PTFLAG = 1	'UKMOTEMP'
2	zenith angles for each apparent altitude (radians). These angular measurements are defined from local zenith down to each FOV angular position.	'APPZENANG'
201	acceleration of gravity for each apparent tangent altitude (m/s/s)	'GRAV_ACC'
206	refraction angle (at 1000cm^{-1}) for each apparent tangent altitude (radians)	'REFRAC'
204	apparent solar extent for each apparent tangent altitude (radians)	'SOLEXT'
205	apparent altitude of the Sun's top edge for each apparent tangent altitude (km)	'APPTOPZ'
5	elapsed time since start of event for each apparent altitude (seconds)	'TIMES'
11	position of the center of the instrument boresight on the solar disk for each elapsed time (radians down from the top edge)	'FSSPOS'
202	gimble elevation angles for each elapsed time (radians)	'GIMBLE'
203	gimble zenith angles for each elapsed time (radians)	'GIMBLZ'
207	spacecraft subtangent latitude for each elapsed time (deg)	'SCLATS'
208	spacecraft subtangent longitude for each elapsed time (deg)	'SCLONS'
223	spacecraft altitude for each elapsed time (km)	'SCALTS'
224	Instrument VPEAK signal (Volts)	'VPEAK'
225	Boresight correction using the VPEAK signal (Volts)	'VPCOR'
6	spacecraft velocity relative to the sun for each elapsed time (km/s along line of sight). >0 is increasing separation distance	'LOSVELSUN'

INDEX	CONTENTS	LABEL
7	spacecraft velocity relative to the apparent tangent point for each elapsed time (km/s along line of sight) >0 is increasing separation distance	'LOSVELATM'
159	CO_2 boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTCO2'
160	H_2O boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTH2O'
161	NO_2 boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTNO2'
162	O_3 boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTO3'
163	CH_4 boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTCH4'
164	CH_4D boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTDCH4'
165	HCl boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTHCL'
166	HClD boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTDHCL'
167	NO boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTNO'
168	NOD boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTDNO'
169	HF boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTHF'
170	HFD boresight position on the solar disk for each apparent altitude (radians down from the top edge)	'LINTDHF'
12	CO_2 signal at each apparent altitude (volts)	'INTCO2'
13	H_2O signal at each apparent altitude (volts)	'INTH2O'
14	NO_2 signal at each apparent altitude (volts)	'INTNO2'
15	O_3 signal at each apparent altitude (volts)	'INTO3'
16	CH_4 signal at each apparent altitude (volts)	'INTCH4'
17	CH_4 difference signal at each apparent altitude (volts)	'INTDCH4'
18	HCL signal at each apparent altitude (volts)	'INTHCL'

INDEX	CONTENTS	LABEL
19	HCL difference signal at each apparent altitude (volts)	'INTDHCL'
20	NO signal at each apparent altitude (volts)	'INTNO'
21	NO difference signal at each apparent altitude (volts)	'INTDNO'
22	HF signal at each apparent altitude (volts)	'INTHF'
23	HF difference signal at each apparent altitude (volts)	'INTDHF'
155	SMTON (12), 1 if channel is filtered. The channel order is the same as in the signal array.	'SMTON'
156	SMTF(12), noise reduction factor for channel. The channel order is the same as in the signal array.	'SMTF'
157	SMTP(12), noise/signal desired for channel. The channel order is the same as in the signal array.	'SMTP'
158	IFILT(12) smoothing for channel: 1 if smoothed and 0 if no smoothing. The channel order is the same as in the signal array.	'IFILT'
24	Normalized CO_2V solar limb darkening curve	'LDCO2'
25	Normalized H_2OV solar limb darkening curve	'LDH2O'
26	Normalized NO_2V solar limb darkening curve	'LDNO2'
27	Normalized O_3V solar limb darkening curve	'LDO3'
28	Normalized CH_4V solar limb darkening curve	'LDCH4'
29	Normalized HClV solar limb darkening curve	'LDHCL'
30	Normalized NOV solar limb darkening curve	'LDNO'
31	Normalized HFV solar limb darkening curve	'LDHF'
173	Normalized CH_4DV solar limb darkening curve	'LDCH4D'
174	Normalized HClDV solar limb darkening curve	'LDHCLD'
175	Normalized NODV solar limb darkening curve	'LDNOD'
176	Normalized HFDV solar limb darkening curve	'LDHFD'
177	Residual difference limb darkening curve CO_2V	'DLDCO2'
178	Residual difference limb darkening curve H_2OV	'DLDH2O'
179	Residual difference limb darkening curve NO_2V	'DLDNO2'
180	Residual difference limb darkening curve O_3V	'DLDO3'
181	Residual difference limb darkening curve CH_4V	'DLDCH4'

INDEX	CONTENTS	LABEL
182	Residual difference limb darkening curve CH_4DV	'DLDCH4D'
183	Residual difference limb darkening curve HCLV	'DLDHCL'
184	Residual difference limb darkening curve HCLDV	'DLDHCLD'
185	Residual difference limb darkening curve NOV	'DLDNO'
186	Residual difference limb darkening curve NODV	'DLDNOD'
187	Residual difference limb darkening curve HFV	'DLDHF'
188	Residual difference limb darkening curve HFDV	'DLDHFD'
171	RMS Error for each channel of the DLDXXX array	'ELD'
172	Max Error for each channel of the DLDXXX array	'EMLD'
189	CO_2 sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTCO2'
190	H_2O sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTH2O'
191	NO_2 sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTNO2'
192	O_3 sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTO3'
193	CH_4 sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTCH4'
194	CH_4DV sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTCH4D'
195	HCl sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTHCL'
196	HClDV sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTHCLD'
197	NO sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTNO'
198	NODV sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTNOD'
199	HF sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTHF'
200	HFDV sunspot residual in noise units for channel. This parameter may not be reliable.	'SPOTHFD'
139	Off-Sun offset (volts) in order below CO_2, H_2O, NO_2, O_3, CH_4, DCH_4, HCl, DHCl, NO,	'OFFSUN'

INDEX	CONTENTS	LABEL
	DNO, HF, DHF	
32	CO_2 (press/temp) retrieval: pressure (mb)	'PRCO2'
33	CO_2 (press/temp) retrieval: altitude (km)	'ALTCO2'
34	CO_2 (press/temp) retrieval: temperature (K)	'TEMPCO2'
35	CO_2 (press/temp) retrieval: volume mixing ratio	'XMIXCO2'
36	CO_2 (press/temp) retrieval: quality profiles	'QUALCO2'
128	CO_2 (press/temp) retrieval: retrieval flag	'RFLGCO2'
37	CO_2 (press/temp) retrieval: aerosol transmission	N/A
38	CO_2 (press/temp) retrieval: aerosol extinction (1/km)	'AEXCO2'
39	CO_2 (press/temp) retrieval: column sum (molec/cm^2)	'CO2 CS'
140	CO_2 (press/temp) retrieval: refraction factor	'RF CO2'
40	H_2O retrieval: pressure (mb)	'PRH2O'
41	H_2O retrieval: altitude (km)	'ALTH2O'
42	H_2O retrieval: temperature (K)	'TEMPH2O'
43	H_2O retrieval: volume mixing ratio	'XMIXH2O'
44	HO retrieval: quality profiles	'QUALH2O'
129	H_2O retrieval: retrieval flag	'RFLGH2O'
45	H_2O retrieval: aerosol transmission	N/A
46	H_2O retrieval: aerosol extinction (1/km)	'AEXH2O'
138	H_2O retrieval: column sum (molec/cm^2)	'H2O CS'
141	H_2O retrieval: refraction factor	'RF H2O'
48	NO_2 retrieval: pressure (mb)	'PRNO2'
49	NO_2 retrieval: altitude (km)	'ALTNO2'
50	NO_2 retrieval: temperature (K)	'TEMPNO2'
51	NO_2 retrieval: volume mixing ratio	'XMIXNO2'
52	NO_2 retrieval: quality profiles	'QUALNO2'
130	NO_2 retrieval: retrieval flag	'RFLGNO2'
53	NO_2 retrieval: aerosol transmission	N/A
54	NO_2 retrieval: aerosol extinction (1/km)	'AEXNO2'
55	NO_2 retrieval: column sum (molec/cm^2)	'NO2 CS'
142	NO_2 retrieval: refraction factor	'RF NO2'

INDEX	CONTENTS	LABEL
56	O_3 retrieval: pressure (mb)	'PRO3'
57	O_3 retrieval: altitude (km)	'ALTO3'
58	O_3 retrieval: temperature (K)	'TEMPO3'
59	O_3 retrieval: volume mixing ratio	'XMIXO3'
60	O_3 retrieval: quality profiles	'QUALO3'
131	O_3 retrieval: retrieval flag	'RFLGO3'
61	O_3 retrieval: aerosol transmission	N/A
62	O_3 retrieval: aerosol extinction (1/km)	'AEXO3'
63	O_3 retrieval: column sum (molec/cm^2)	'O3 CS'
143	O_3 retrieval: refraction factor	'RF O3'
64	NO retrieval: pressure (mb)	'PRNO'
65	NO retrieval: altitude (km)	'ALTNO'
66	NO retrieval: temperature (K)	'TEMPNO'
67	NO retrieval: volume mixing ratio	'XMIXNO'
68	NO retrieval: quality profiles	'QUALNO'
132	NO retrieval: retrieval flag	'RFLGNO'
69	NO retrieval: aerosol transmission	N/A
70	NO retrieval: aerosol extinction (1/km)	'AEXNO'
71	NO retrieval: column sum (molec/cm^2)	'NO CS '
144	NO retrieval: refraction factor	'RF NO'
72	DCH_4 retrieval: pressure (mb)	'PRDCH4'
73	DCH_4 retrieval: altitude (km)	'ALTDCH4'
74	DCH_4 retrieval: temperature (K)	'TEMPDCH4'
75	DCH_4 retrieval: volume mixing ratio	'XMIXDCH4'
76	DCH_4 retrieval: quality profiles	'QUALDCH4'
133	DCH_4 retrieval: retrieval flag	'RFLGDCH4'
77	DCH_4 retrieval: aerosol transmission	N/A
78	DCH_4 retrieval: aerosol extinction (1/km)	'AEXDCH4'
79	DCH_4 retrieval: column sum (molec/cm^2)	'DCH4 CS'
145	DCH_4 retrieval: refraction factor	'RF DCH4'
80	CH_4 (HCl V) retrieval: pressure (mb)	N/A

INDEX	CONTENTS	LABEL
81	CH_4 (HCl V) retrieval: altitude (km)	N/A
82	CH_4 (HCl V) retrieval: temperature (K)	N/A
83	CH_4 (HCl V) retrieval: volume mixing ratio	N/A
84	CH_4 (HCl V) retrieval: quality profiles	N/A
134	CH_4 (HCl V) retrieval: retrieval flag	N/A
85	CH_4 (HCl V) retrieval: aerosol transmission	N/A
86	CH_4 (HCl V) retrieval: aerosol extinction (1/km)	N/A
87	CH_4 (HCl V) retrieval: column sum (molec/cm^2)	N/A
146	CH_4 (HCl V) retrieval: refraction factor	N/A
88	CH_4 (CH_4 V) retrieval: pressure (mb)	N/A
89	CH_4 (CH_4 V) retrieval: altitude (km)	N/A
90	CH_4 (CH_4 V) retrieval: temperature (K)	N/A
91	CH_4 (CH_4 V) retrieval: volume mixing ratio	N/A
92	CH_4 (CH_4 V) retrieval: quality profiles	N/A
135	CH_4 (CH_4 V) retrieval: retrieval flag	N/A
93	CH_4 (CH_4 V) retrieval: aerosol transmission	N/A
94	CH_4 (CH_4 V) retrieval: aerosol extinction (1/km)	N/A
95	CH_4 (CH_4 V) retrieval: column sum (molec/cm^2)	N/A
147	CH_4 (CH_4 V) retrieval: refraction factor	N/A
96	CH_4 (merged) retrieval: pressure (mb)	'PRCH4M'
97	CH_4 (merged) retrieval: altitude (km)	'ALTCH4M'
98	CH_4 (merged) retrieval: temperature (K)	'TEMPCH4M'
99	CH_4 (merged) retrieval: volume mixing ratio. This is the CH_4 DV profile (item #75) merged with climatology.	'XMIXCH4M'
100	CH_4 (merged) retrieval: quality profiles	N/A
101	CH_4 (merged) retrieval: column sum (molec/cm^2)	'CH4/MRG CS'
102	HCL retrieval: pressure (mb)	'PRHCL'
103	HCl retrieval: altitude (km)	'ALTHCL'
104	HCl retrieval: temperature (K)	'TEMPHCL'
105	HCl retrieval: volume mixing ratio	'XMIXHCL'

INDEX	CONTENTS	LABEL
106	HCl retrieval: quality profiles	'QUALHCL'
136	HCl retrieval: retrieval flag	'RFLGHCL'
107	HCl retrieval: aerosol transmission	N/A
108	HCl retrieval: aerosol extinction (1/km)	'AEXHCL'
109	HCl retrieval: column sum (molec/cm^2)	'HCL CS'
148	HCl retrieval: refraction factor	'RF HCL'
110	HF retrieval: pressure (mb)	'PRHF'
111	HF retrieval: altitude (km)	'ALTHF'
112	HF retrieval: temperature (K)	'TEMPHF'
113	HF retrieval: volume mixing ratio	'XMIXHF'
114	HF retrieval: quality profiles	'QUALHF'
137	HF retrieval: retrieval flag	'RFLGHF'
115	HF retrieval: aerosol transmission	N/A
116	HF retrieval: aerosol extinction (1/km)	'AEXHF'
117	HF retrieval: column sum (molec/cm^2)	'HF CS'
149	HF retrieval: refraction factor	'RF HF'
118	Interfering gas profile: pressure (mb)	'IGPR'
119	Interfering gas profile: altitude (km)	'IGALT'
120	Interfering gas profile: temperature (K)	'IGTEMP'
121	Interfering gas profile: volume mixing ratio (N_2O)	'IGN2O'
122	Interfering gas profile: quality profiles	N/A
123	Interfering gas profile: aerosol transmission	N/A
124	Interfering gas profile: aerosol extinction (1/km)	N/A
125	interfering gas profile: column sum (molec/cm^2)	'IG CS'
150	temperature at 0.3 km spacing (K)	'LV2TEMP'
151	pressure at 0.3 km spacing (K)	'LV2PRES'
152	temperature used for aerosol removal	N/A
153	pressure used for aerosol removal	N/A
154	Altitude used for aerosol removal	N/A
210	Aerosol retrieval: pressure (mb)	'aero p'
209	Aerosol retrieval: altitude (km)	'aero z'

INDEX	CONTENTS	LABEL
211	Aerosol retrieval: temperature (K)	'aero t'
212	Aerosol retrieval: H_2SO_4 Percentage by weight	'aero h2so4'
213	NO aerosol extinction (1/km)	'aExHi NO'
214	NO AEROSOL EXTINCTION UNCERTIANTIES (1/KM)	'aerStd NO'
215	CH_4 aerosol extinction (1/km)	'aExHi CH4'
216	CH_4 aerosol extinction uncertainties (1/km)	'aerStd CH4'
217	HCl aerosol extinction (1/km)	'aExHi HCl'
218	HCl aerosol extinction uncertainties (1/km)	'aerStd HCl'
219	HF aerosol extinction (1/km)	'aExHi HF'
220	HF aerosol extinction uncertainties (1/km)	'aerStd HF'
221	CO_2 aerosol extinction (1/km)	N/A
222	CO_2 aerosol extinction uncertainties (1/km)	N/A
228	Aerosol Density (g/cm^3)	'AERO_DENSI'
229	Aerosol Median Radius (micron)	'MEDIAN_RAD'
230	Aerosol Distribution Width	'DIST_WIDTH'
231	Concentration (/cm^3)	'CONCENTRAT'
232	Aerosol Surface Area (micron^2 /cm^3)	'SFC_AREA'
233	Aerosol Volume (micron^3 /cm^3)	'VOLUME'
234	Effective Radius (micron)	'EFFEC_RAD'
226	NO_2 Slant Path column amount	'SLPATH_NO2'
227	NO Slant Path Column amount	'SLPATH_NO'
NOTE: THE QUALITY FIELDS ARE IN TERMS OF STANDARD DEVIATIONS AND REPRESENT A PRECISION ESTIMATE OF THE DATA, NOT ACCURACY.		

Appendix 3: Precision Estimates (Quality Numbers)

The "quality" numbers in the HALOE data products are essentially standard deviations used to estimate precision. All species (mixing ratios, aerosol extinctions, and temperature) have these estimates, where the units of the precision estimates are mixing ratio, degrees Kelvin, or extinction. The complete formulation is empirical, although the fundamental steps that the routine CALC_STANDARD DEV follows is described below.

The basic estimate is composed of two terms:

1. A term derived from the estimated measurement uncertainty and the sensitivity of the simulated signal to the retrieved species for each tangent layer.

2. A term that includes error estimates due to errors in the aerosol model and is a function of the aerosol absorption and of the estimated aerosol model error for each tangent layer. This term is included only in the precision estimates for the H_2O, NO_2, and O_3 radiometer retrievals; the gas correlation channels are nearly insensitive to aerosol extinction, so the aerosol error for those channels is set to zero. Of course, this term is not included in the precision estimates for the aerosol retrievals. The temperature retrieval should have only minor aerosol errors, as its retrieval takes place above 30km; therefore, the aerosol component is not included for temperature.

The one-sigma first term (having units of mixing ratio or of extinction) is expressed as

$$\sigma_x = \sqrt{\frac{\sigma_m^2 * \left(dq/dm\right)^2}{Interl}}, \qquad \textit{Eq. 1}$$

where

$\boldsymbol{\sigma_m}$ is the estimated measurement, one-sigma errors, having the following channel-dependent values (in signal units).

Channel	**Measurement Errors**
CO_2 (T)	8.0 E-4
H_2O	8.0E-4
NO_2	8.0E-4
O_3	8.0E-4
NO	6.0E-6
CH4	1.2E-5
HCl	4.0E-6
HF	8.0E-6
NO aerosol	8.0E-4
CH_4 aerosol	8.0E-4
HCl aerosol	8.0E-4
HF aerosol	8.0E-4

dq/dm is the derivative of the species (***q***) with respect to the simulated signal (**m**) for the tangent layer.

Interl is the number of interleaves used in the retrieval and states how many multiple tangent-layer schemes were used in the retrieval. There is a description of this parameter in the main body of the paper. This variable is a channel-dependent with values given in the table below.

Channel	**Number of Interleaves**
CO_2 (T)	1
H_2O	7
NO_2	7
O_3	7
NO	1
CH4	1
HCl	1
HF	1
NO aerosol	7
CH_4 aerosol	7
HCl aerosol	7
HF aerosol	7

In effect, the formulation of Eq. 1 reduces the standard deviation of one interleave to 1/root (*n*), where *n* is the number of interleaves.

The second term, mentioned above, is used to include an error estimate for the aerosol model in the H_2O, NO_2 and O_3 channels, where aerosols are included as an interfering parameter; of course, the gas correlation channels are insensitive to aerosols, so there is no aerosol model used in the aerosol retrievals. This term (units of mixing ratio) is expressed as

$$\sigma_a = (dq/d\tau) * Ab * E, \qquad \textit{Eq. 2}$$

where

dq/dτ is the derivative of the aerosol extinction (***q***) with respect to the simulated channel transmission (***τ***) for the tangent layer,
Ab is the calculated absorption due to aerosol alone for the tangent layer, and
E is the estimated aerosol model error (5% for all 3 channels) for all layers

The above two terms are then combined to give the overall uncertainty in terms of a standard deviation Φ

$$\Phi = sqrt\left[\sigma^2{}_x + \sigma^2{}_a\right] \qquad \textit{Eq. 3}$$

The value of Φ is calculated differently for the temperature retrieval and, in fact, is in error. For this retrieval, Φ is defined as

$$\Phi = \left(N * dT/dm\right)^2, \qquad \textit{Eq. 4}$$

where

N is a channel noise figure (0.0004) in signal units.
dT/dm is the derivative of the temperature (***T***) with respect to the simulated signal (***m***) for the tangent layer.

Note that the value of **N******dT/dm*** is squared in eq. 4, but it should not be; this mistake means that the precision estimates in the files for the temperature are actually the variance of the temperature. They should have a square root function applied to convert them to 1σ uncertainties.

Next, the software checks and determines if the retrieval for the layer failed (no convergence, etc.). If there was a problem with the retrieval, the value of Φ is altered; the value of Φ is set equal to the mixing ratio or extinction (100% error). If there was a problem with the retrieval and it was a temperature retrieval, the value of Φ was **not** altered from the value determined above.

The final step in calculating the standard deviations that are contained in the Level 2 files is to take the standard deviation, Φ, described above plus other parameters and arrive at useful estimates of the precision. Though a rigorous investigation to determine precision estimates was never undertaken, a good approximation based on the Level 1 and Level 2 processing parameters was implemented and that information is what is contained in the HALOE products files. Those values were compared to ones derived from the retrieved products for regions of the atmosphere that exhibited very small variations. These comparisons indicated that the empirical approximations are a reasonably good estimate of the uncertainties. The following parameters are used to estimate the precisions at each tangent point for each species:

(a) The channel dependent noise/signal values (**smtp**) contained in the Level 1 file, which are

Channel	**Noise/signal ratio (smtp)**
CO_2 (T)	0.01
H_2O	0.01
NO_2	0.01
O_3	0.01
NO	0.04
CH4	0.0076
HCl	0.10
HF	0.03
NO aerosol	0.05
CH_4 aerosol	0.01
HCl aerosol	0.03
HF aerosol	0.03

(b) The channel dependent noise reduction factors (**smtf**). These values are used to smooth the signals in an effort to reduce the impact of noise at high altitude. These are

Channel	**Noise reduction factor (smtf)**
CO_2 (T)	6
H_2O	6
NO_2	6
O_3	6

NO	6
CH4	6
HCl	6
HF	6
NO aerosol	6
CH_4 aerosol	6
HCl aerosol	6
HF aerosol	6

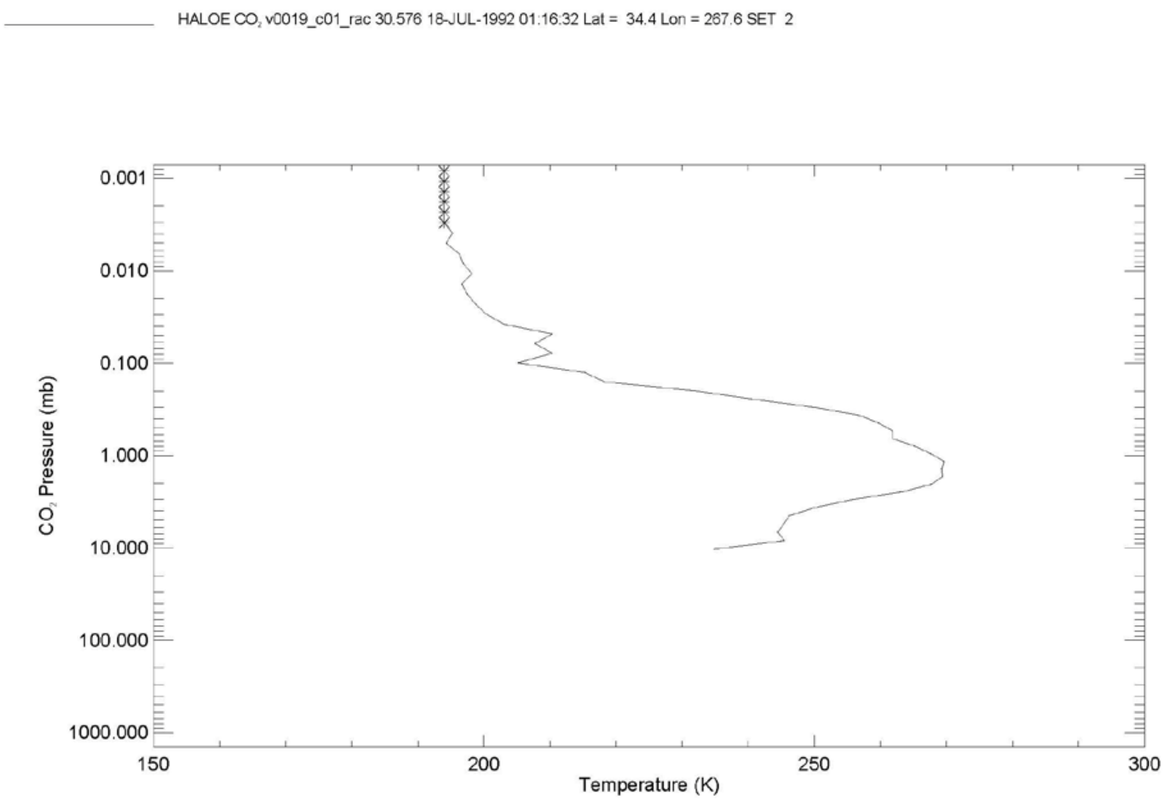
(c) The measurement noise parameter, σ_m, as mentioned above.
(d) The channel absorption for each tangent layer, which is the effective narrow channel of a gas correlation channel (**signal**).
(e) The number of interleaves parameter.
(f) A parameter that specifies the number of points used in smoothing (**nspts**) the retrieved profile in altitude after the retrieval; the smoothing function is a cosine bell applied to the 0.3km spaced H_2O, NO_2, and O_3 profiles only. This step is channel dependent. The values for each channel are given in the table below; a value of zero means no smoothing.

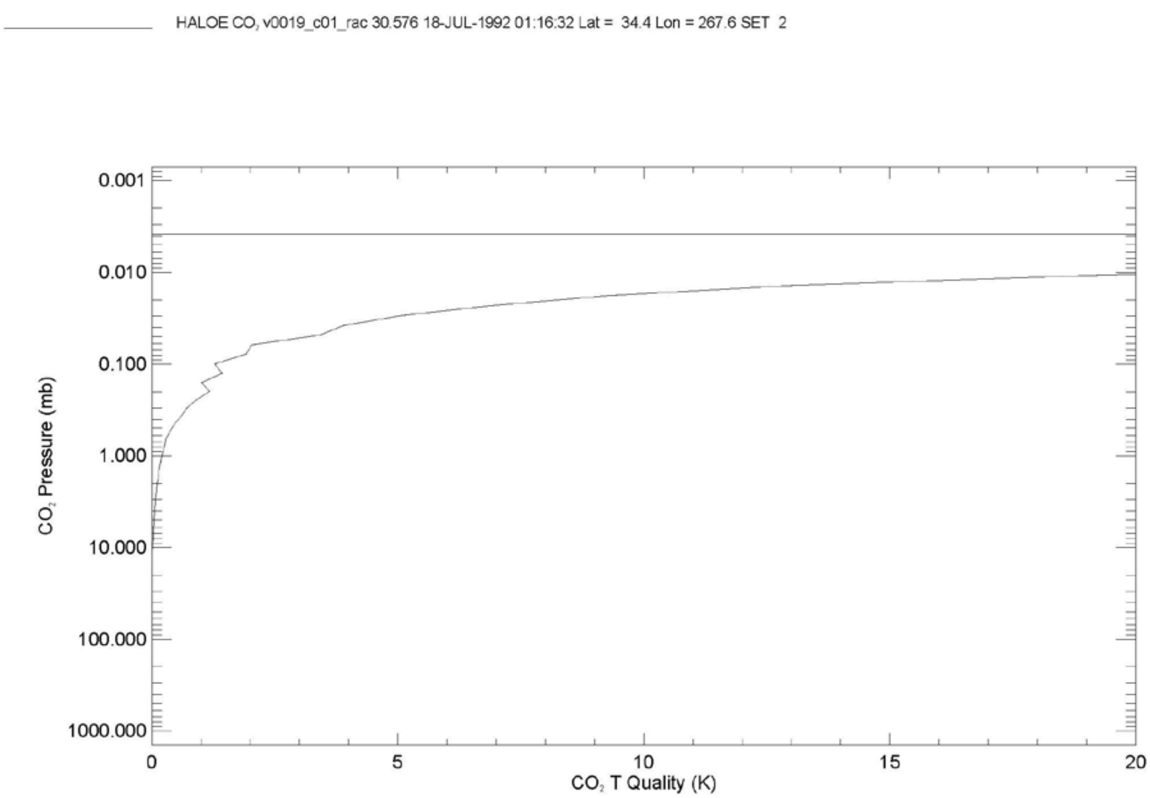
Channel	**Number of points in smoothing (nspts)**
CO_2 (T)	0
H_2O	14
NO_2	14
O_3	14
NO	0
CH4	0
HCl	0
HF	0
NO aerosol	0
CH_4 aerosol	0
HCl aerosol	0
HF aerosol	0

(g) Finally, there are the values of Φ from equations 3 or 4 above.

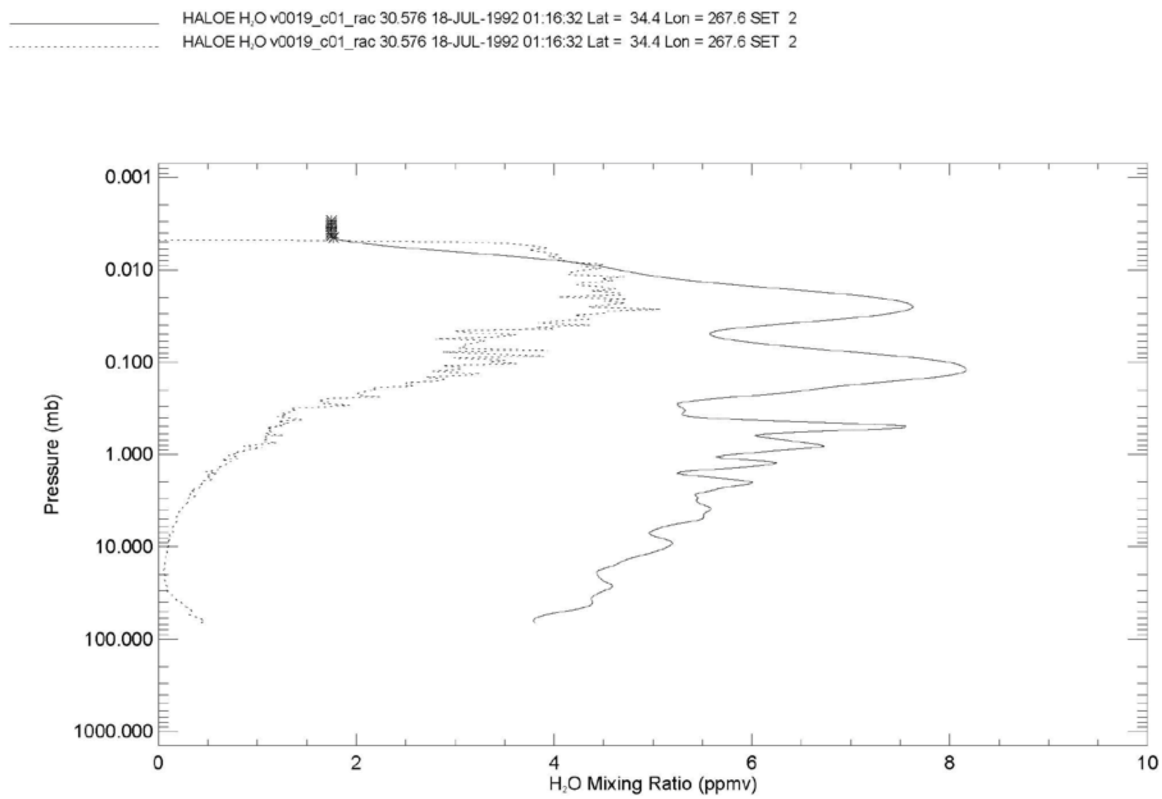
The foregoing parameters are then combined using an empirical algorithm to estimate the precisions. Since this algorithm can lead to a modification of Φ, its values will no longer indicate 100% uncertainty when there are errors. The standard deviations that were determined are included in the Level 2 files for each species and at each tangent layer.

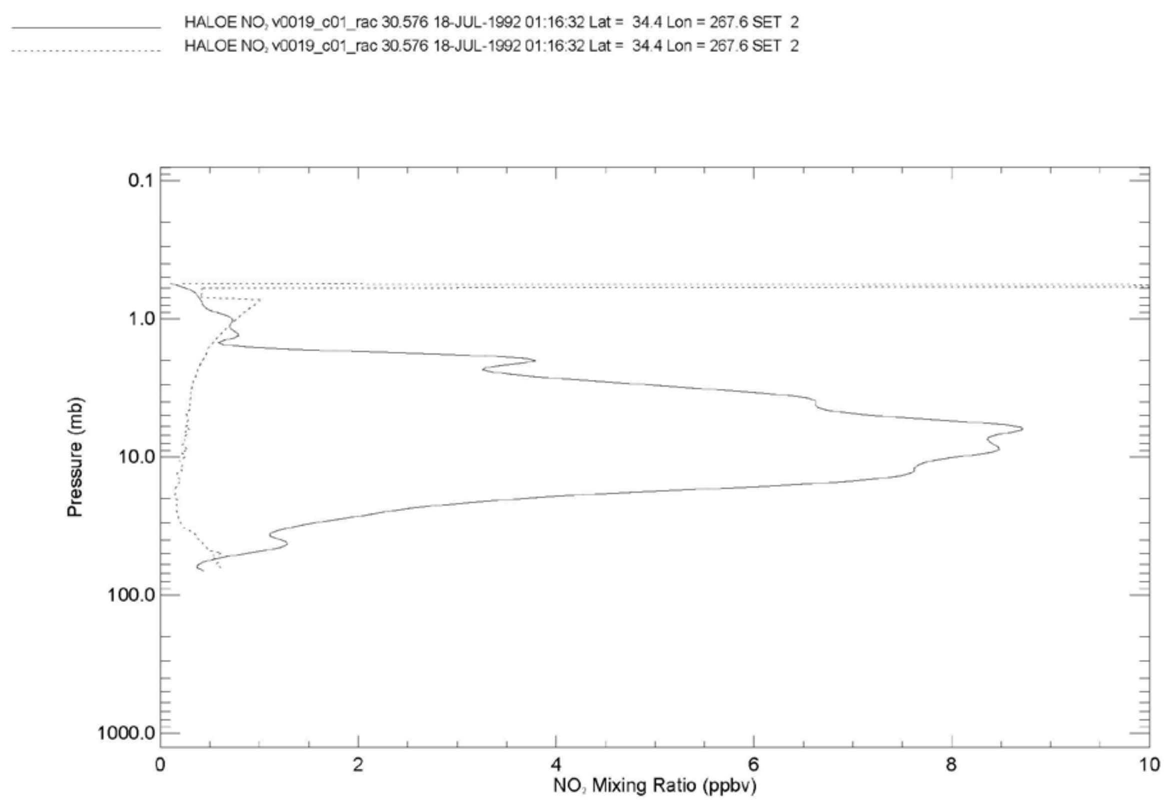
Example plots of retrieved profiles and precision estimates are shown below for set events of two different days. The first day is June 10, 2000 (UARS day 3195) and the other is July 18, 1992 (UARS day 311). The 1992 event was taken during conditions of high volcanic aerosol loading following the eruption of Mount Pinatubo, while the 2000 event has background aerosol amounts. Comparison of the precision estimates at the lower altitudes for the radiometer channels illustrates the impact of the uncertainties from the aerosol model in the precision estimate of the aerosol term.



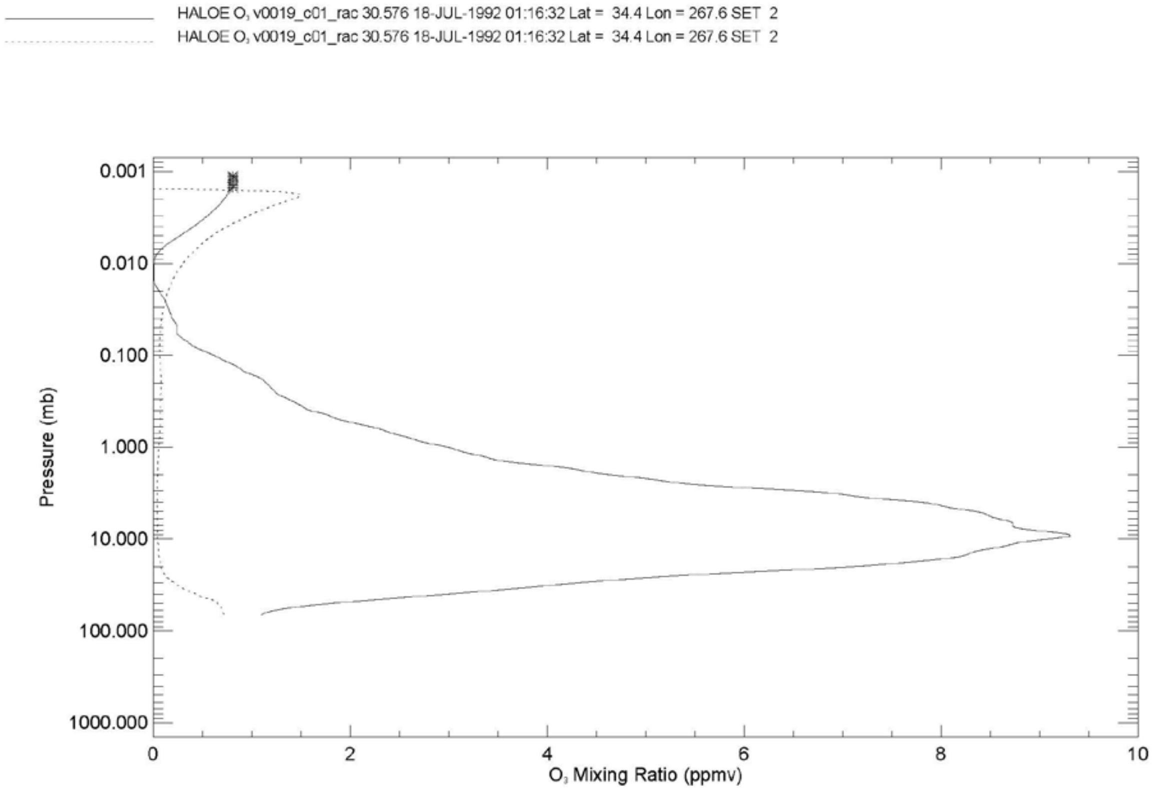


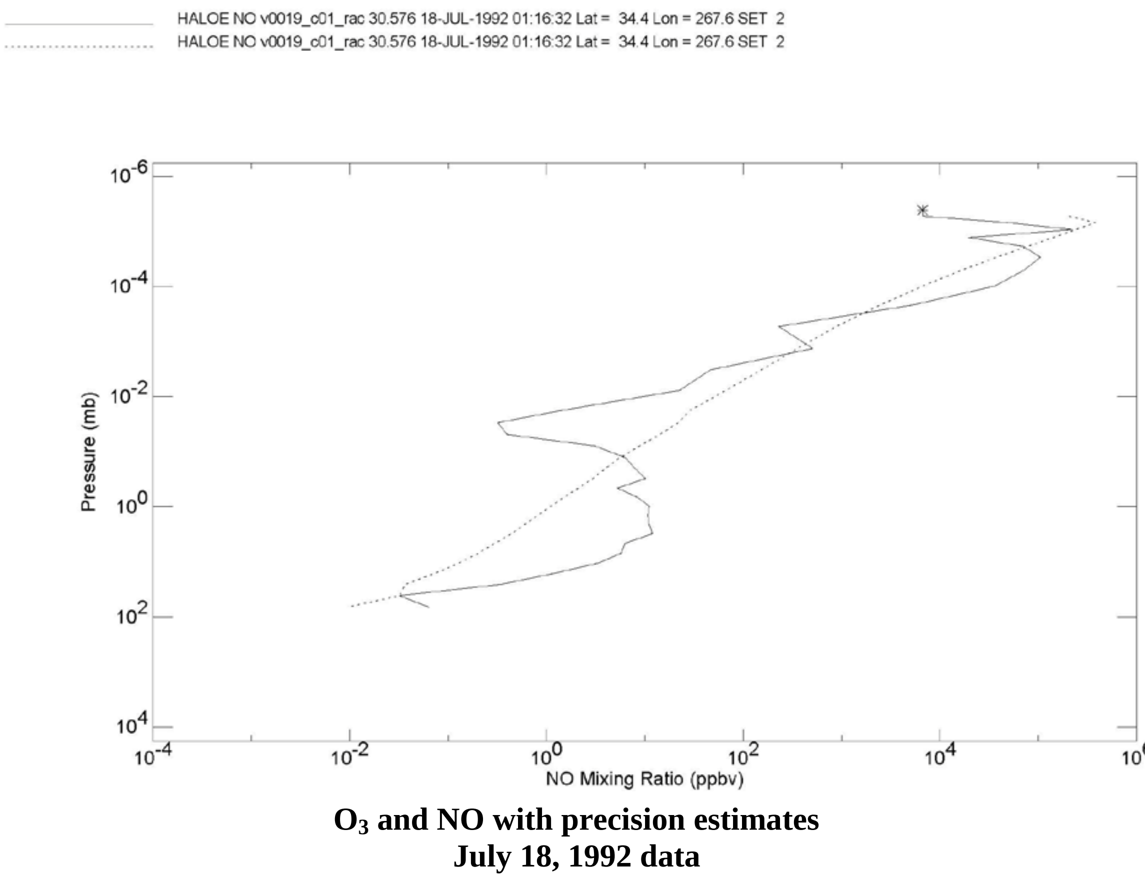
Temperature and temperature precision estimates
July 18, 1992 data



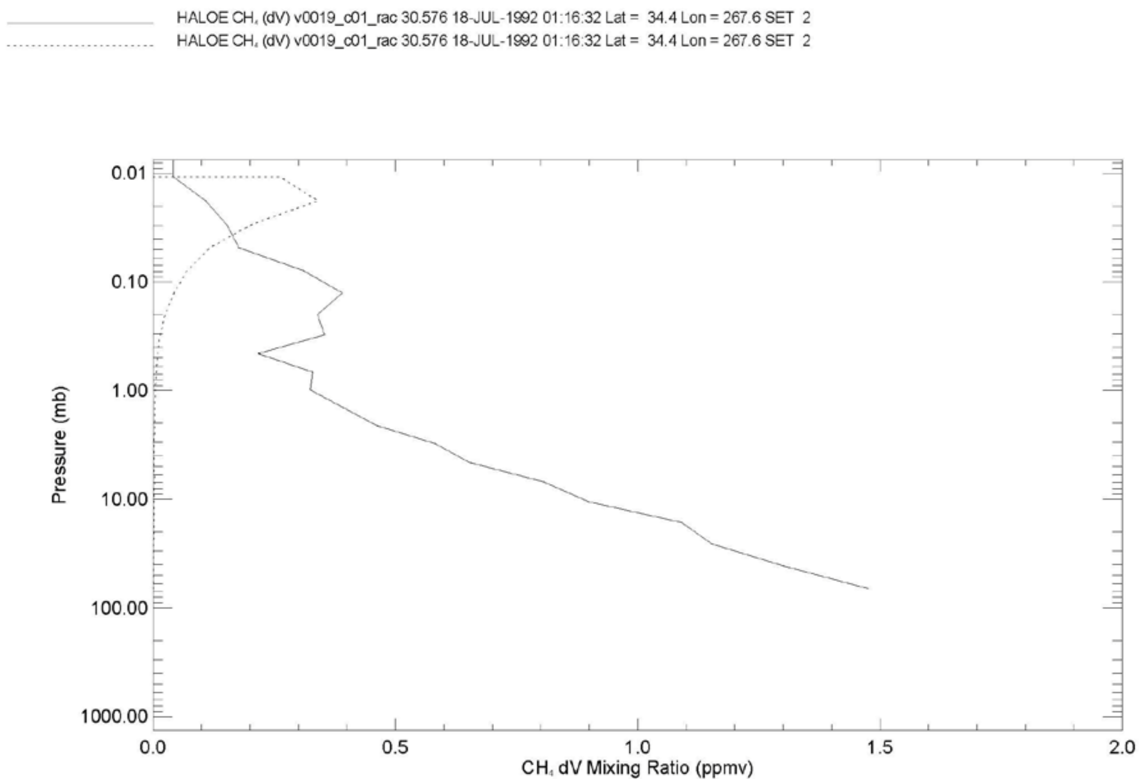


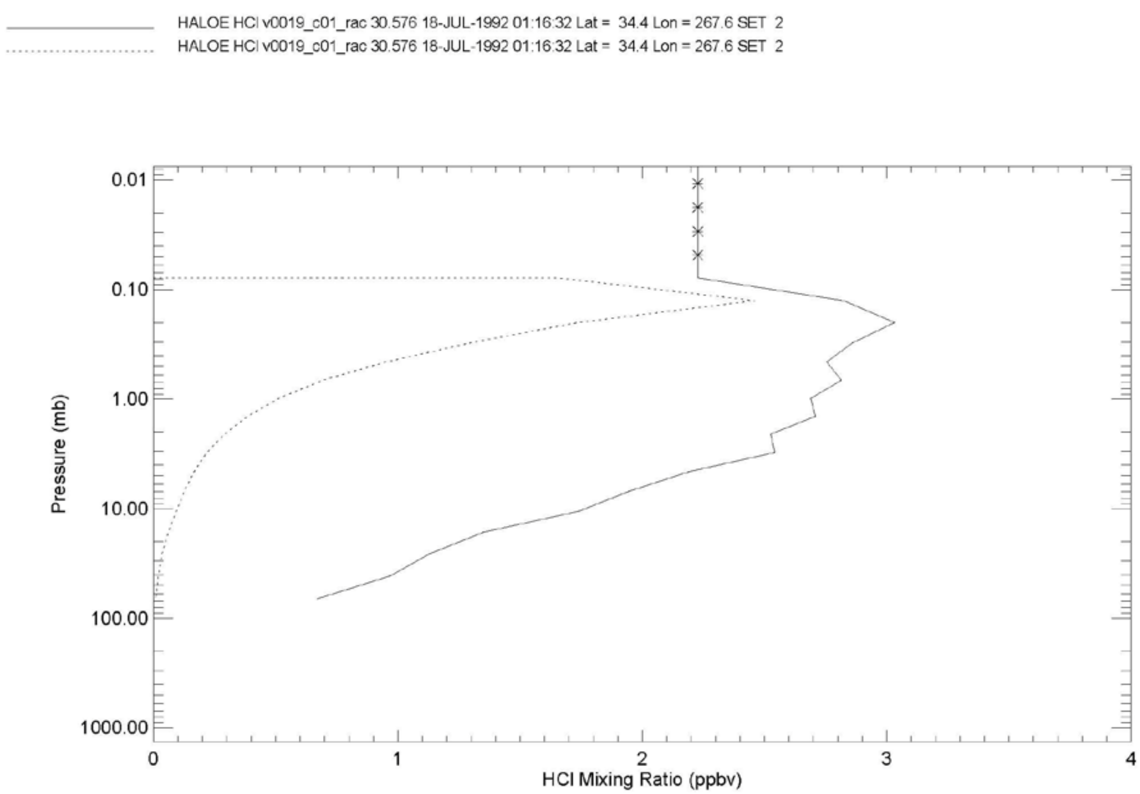
H_2O and NO_2 with precision estimates
July 18, 1992 data



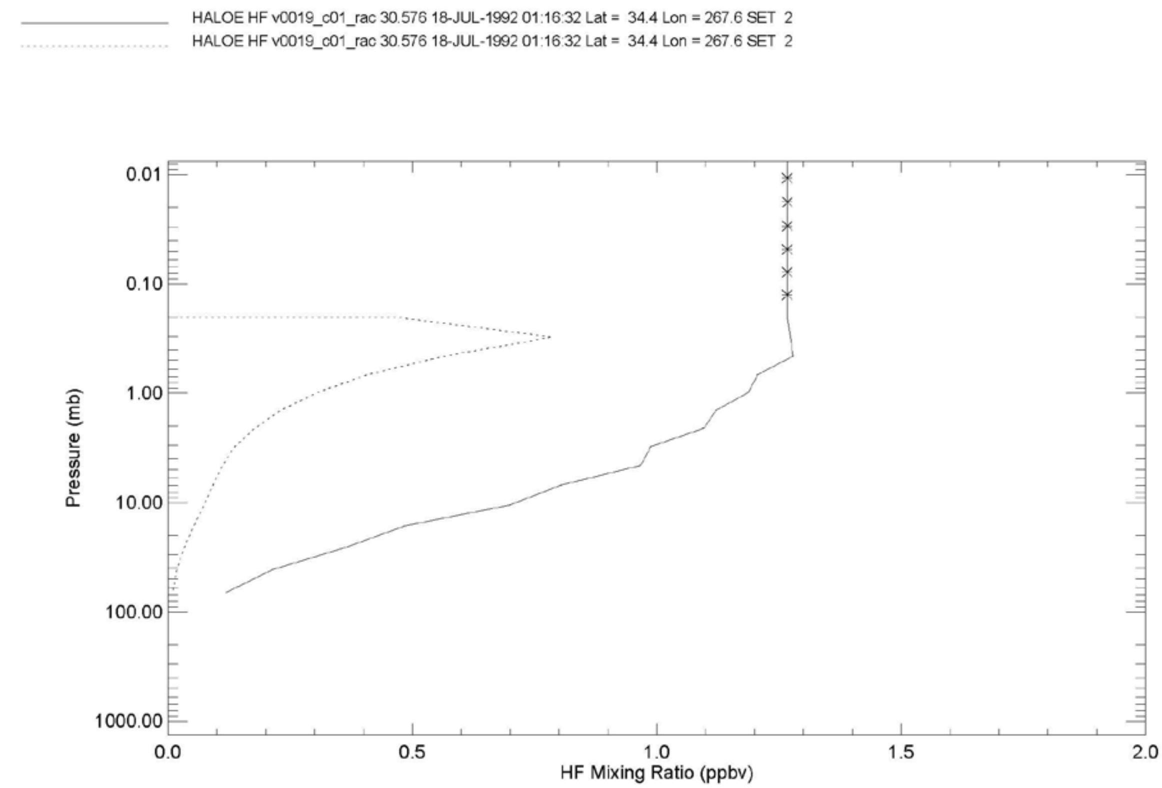


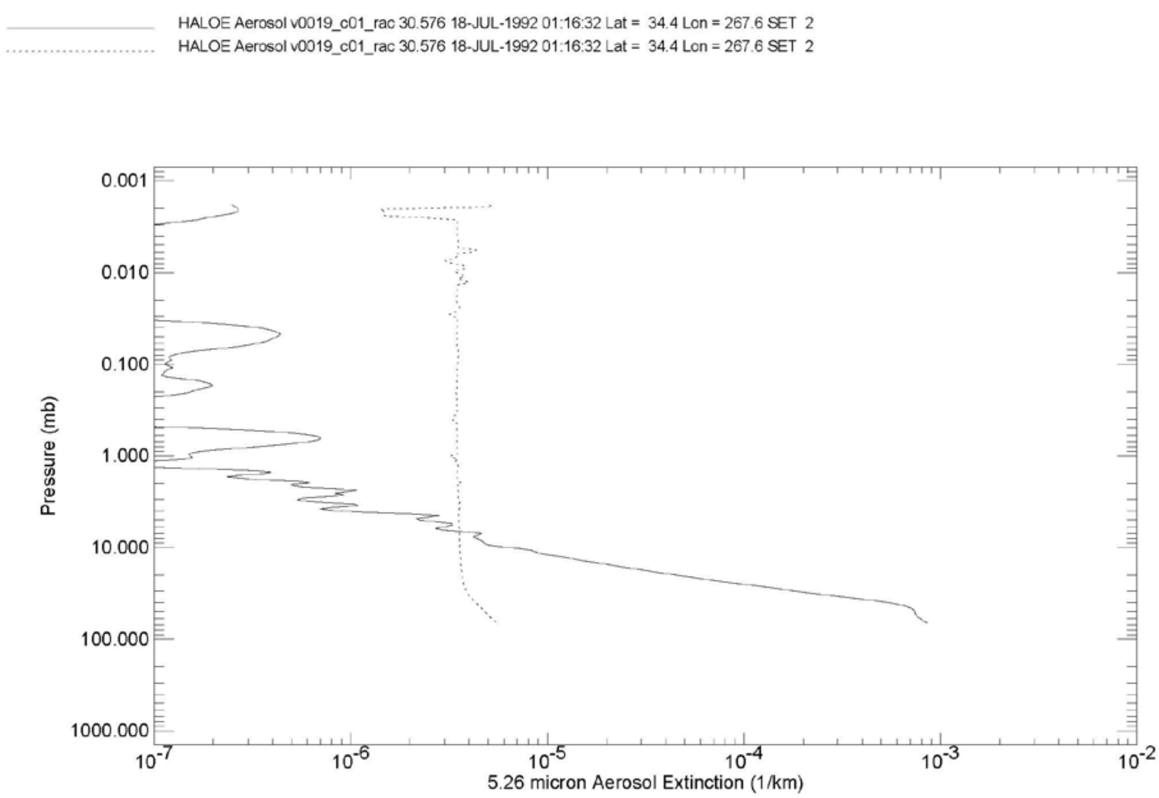
O_3 and NO with precision estimates
July 18, 1992 data



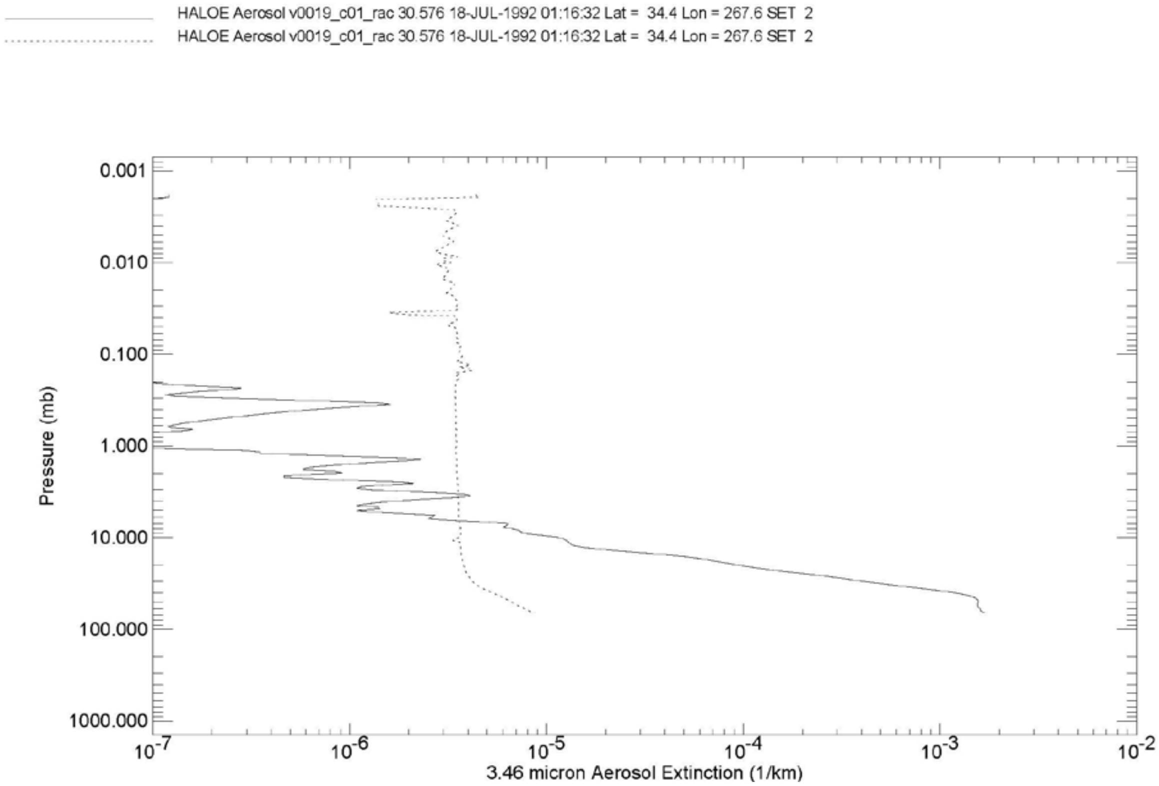


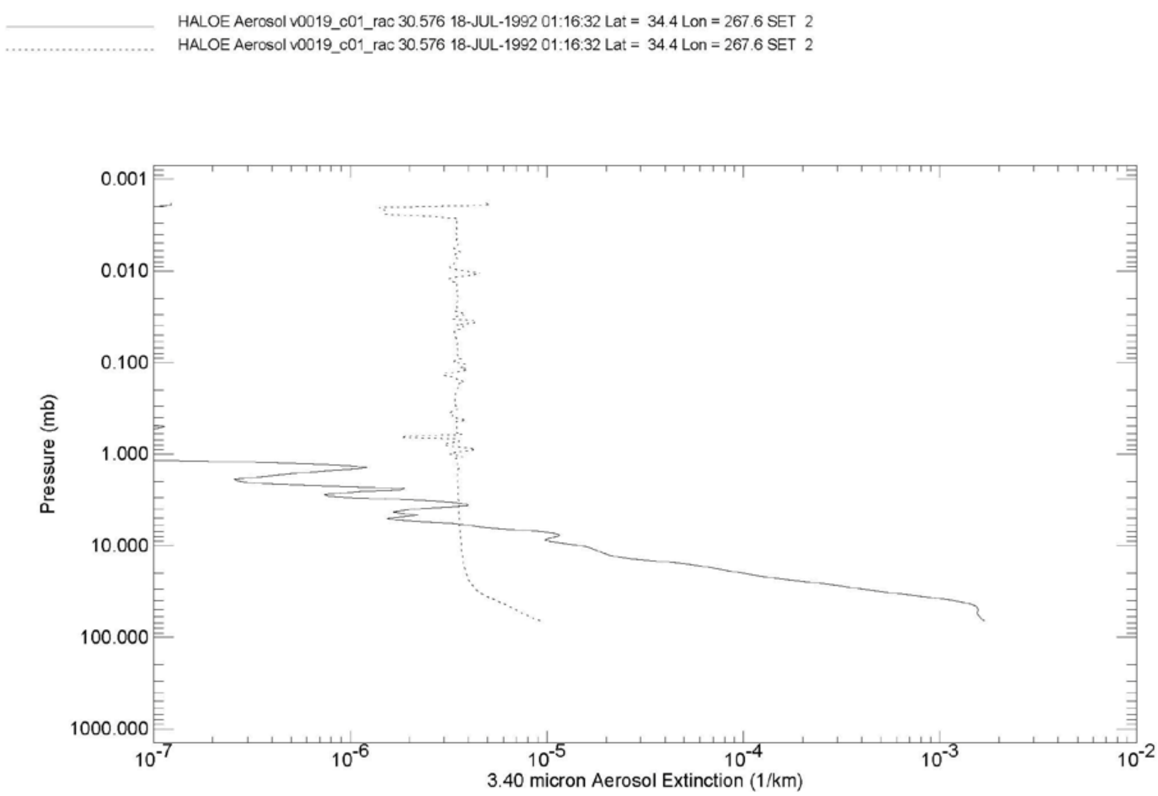
CH_4 and HCl with precision estimates
July 18, 1992 data



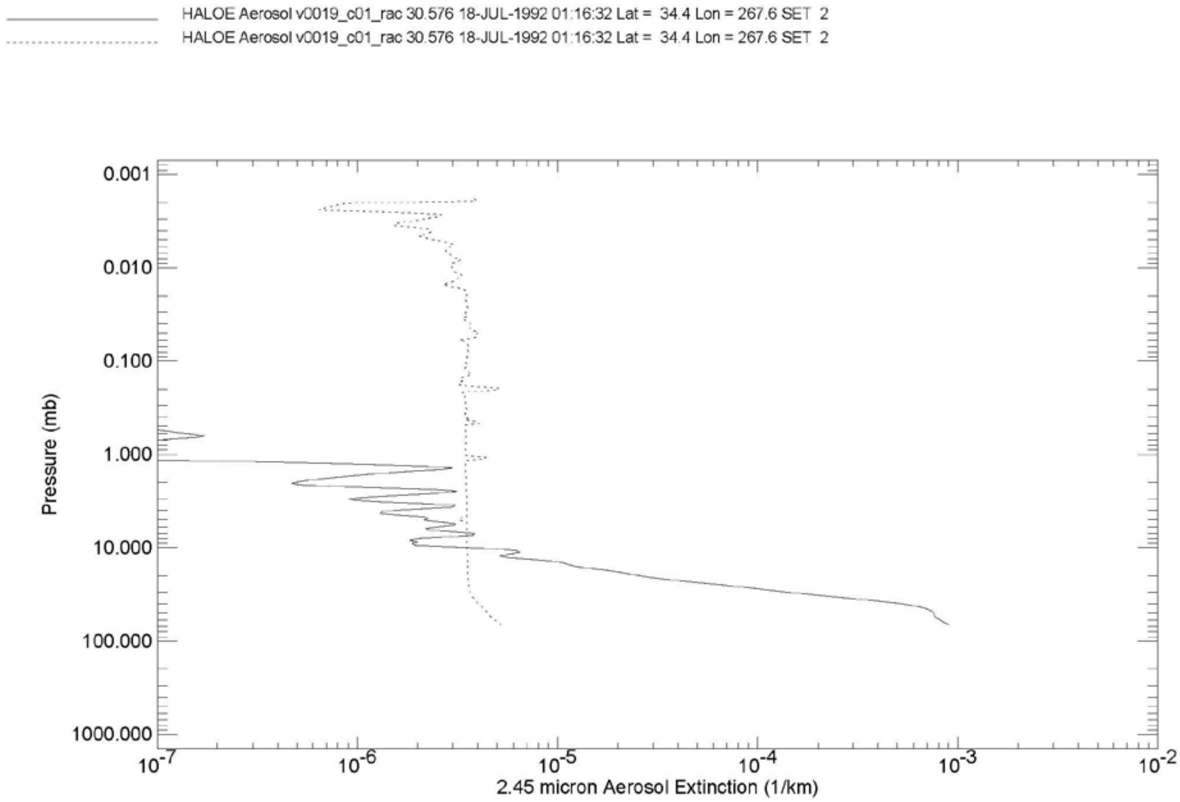


HF and 5.26 micron aerosol with precision estimates
July 18, 1992 data

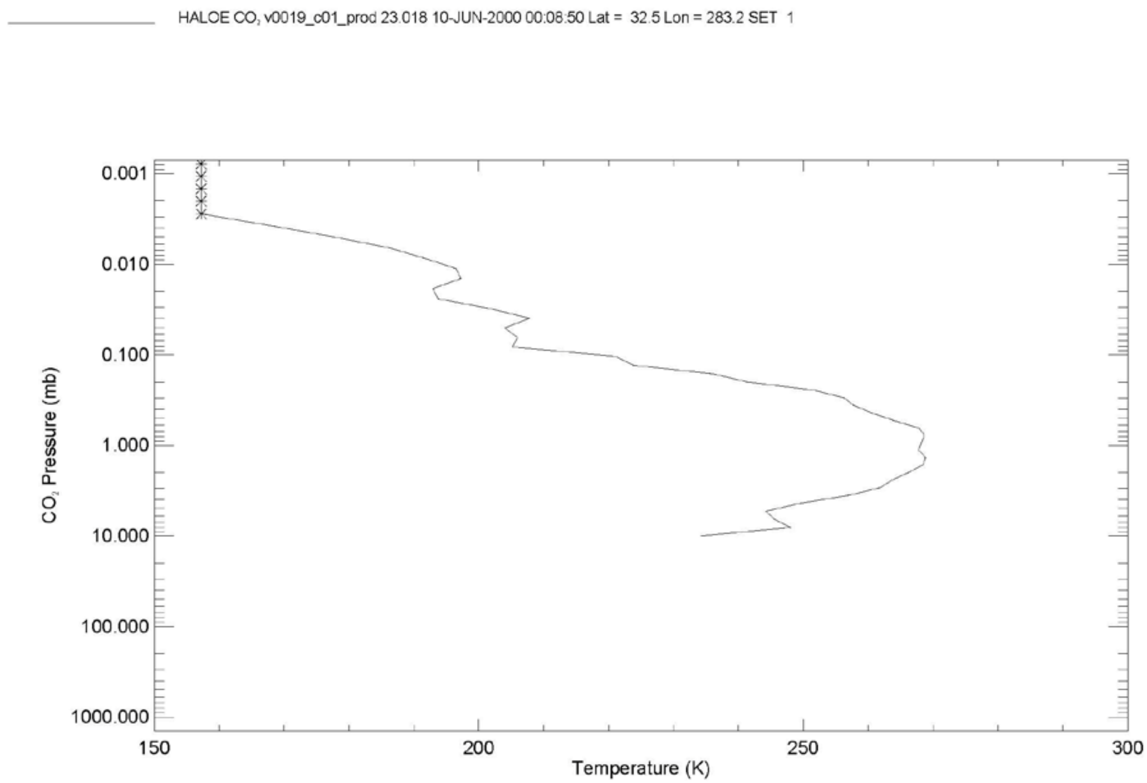


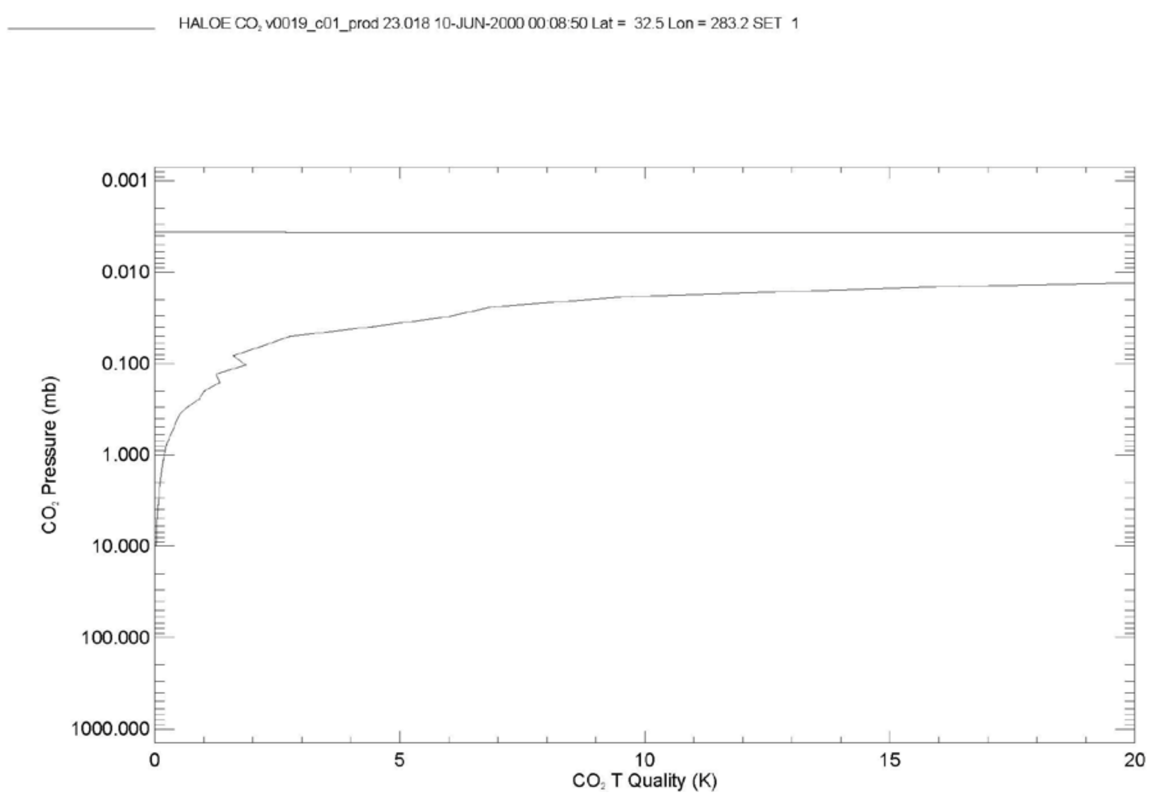


3.46 and 3.40 micron aerosols with precision estimates
July 18, 1992 data

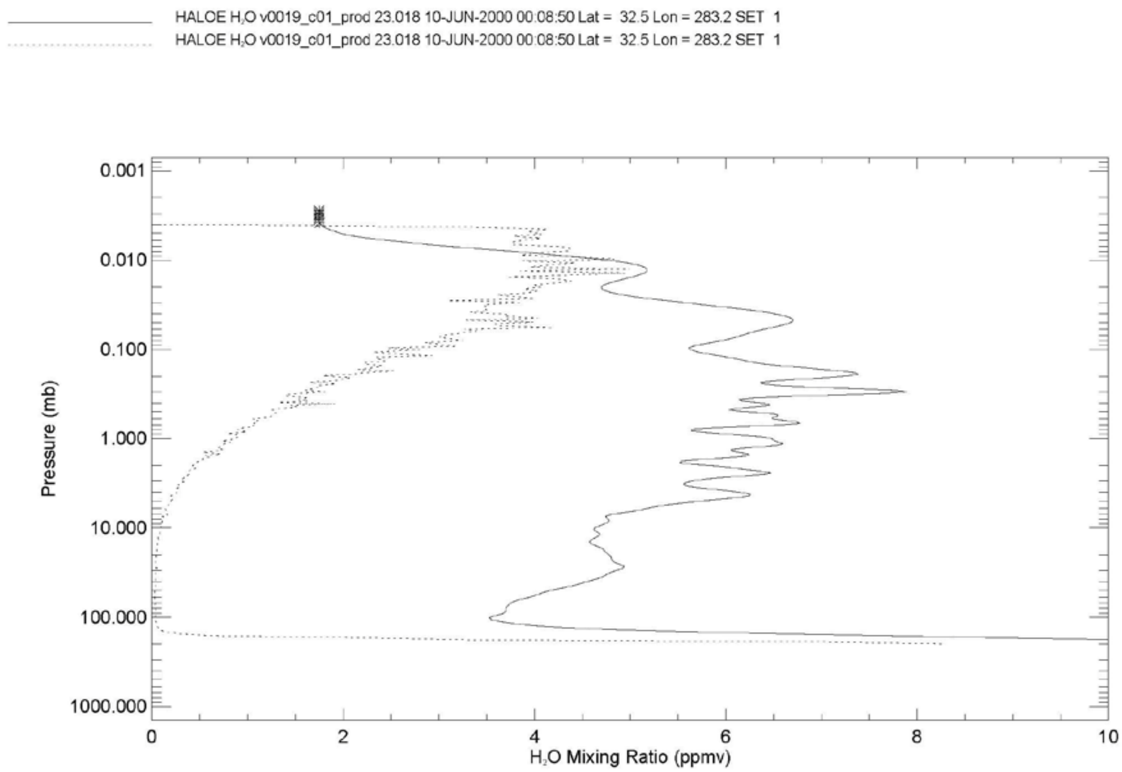


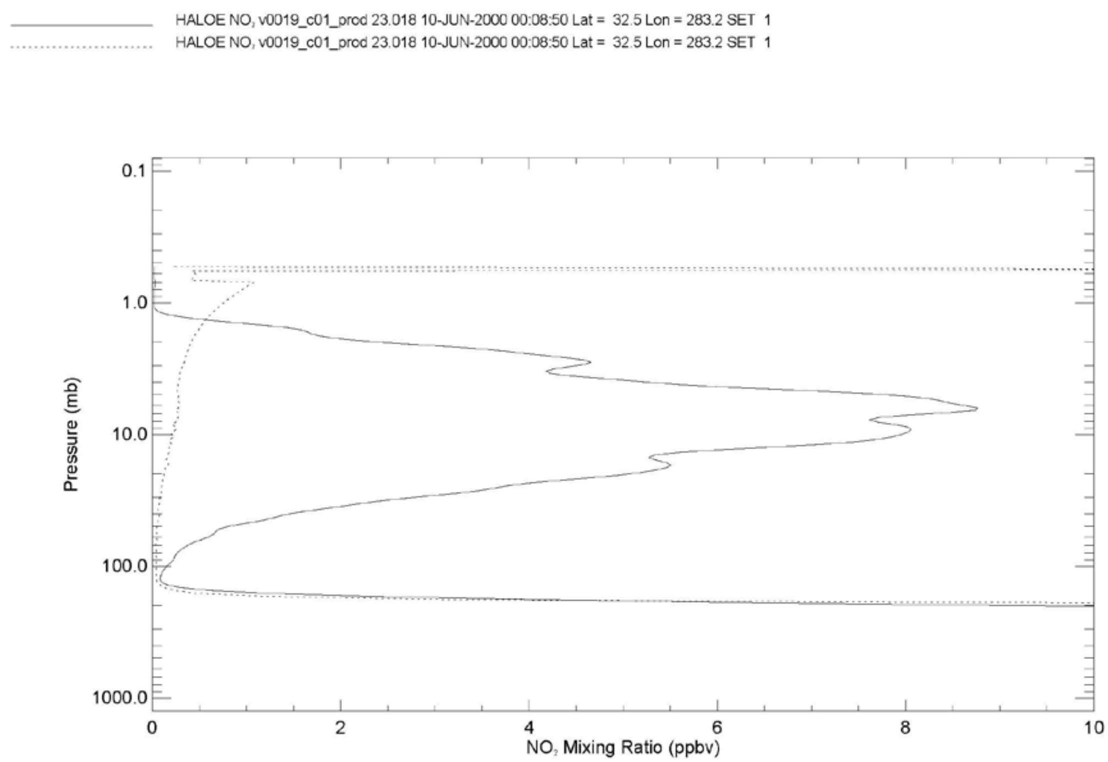
2.45 micron aerosol with precision estimate
July 18, 1992 data



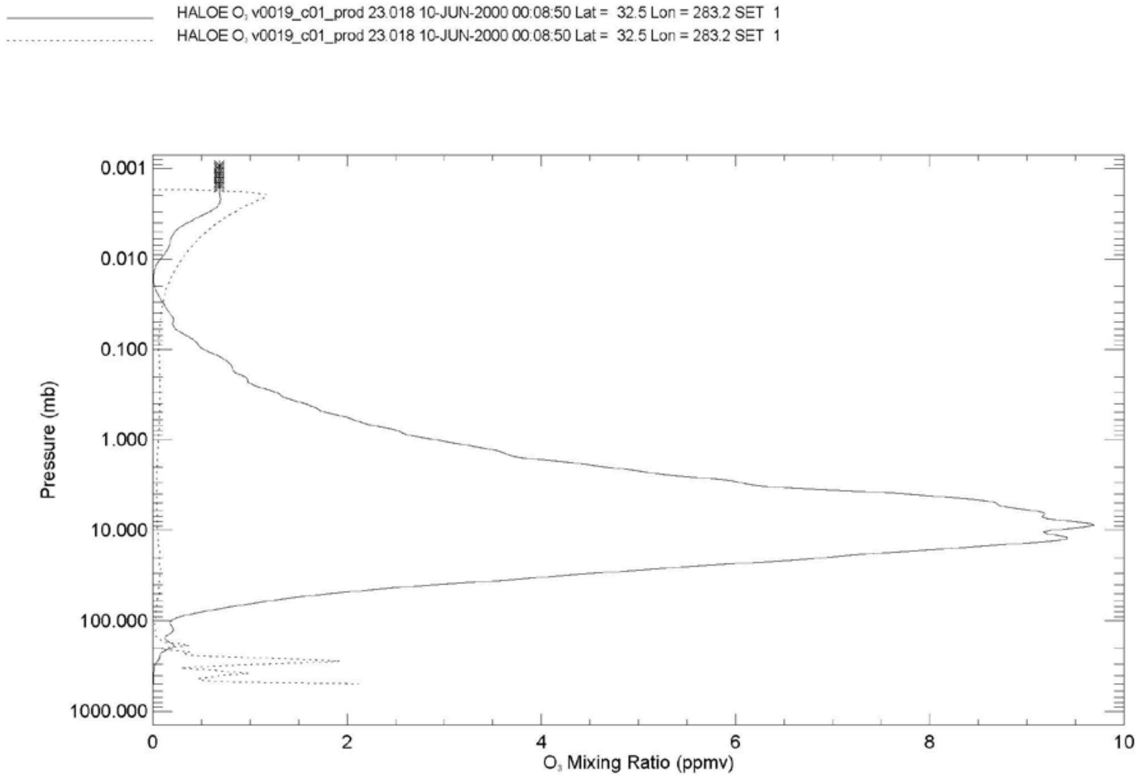


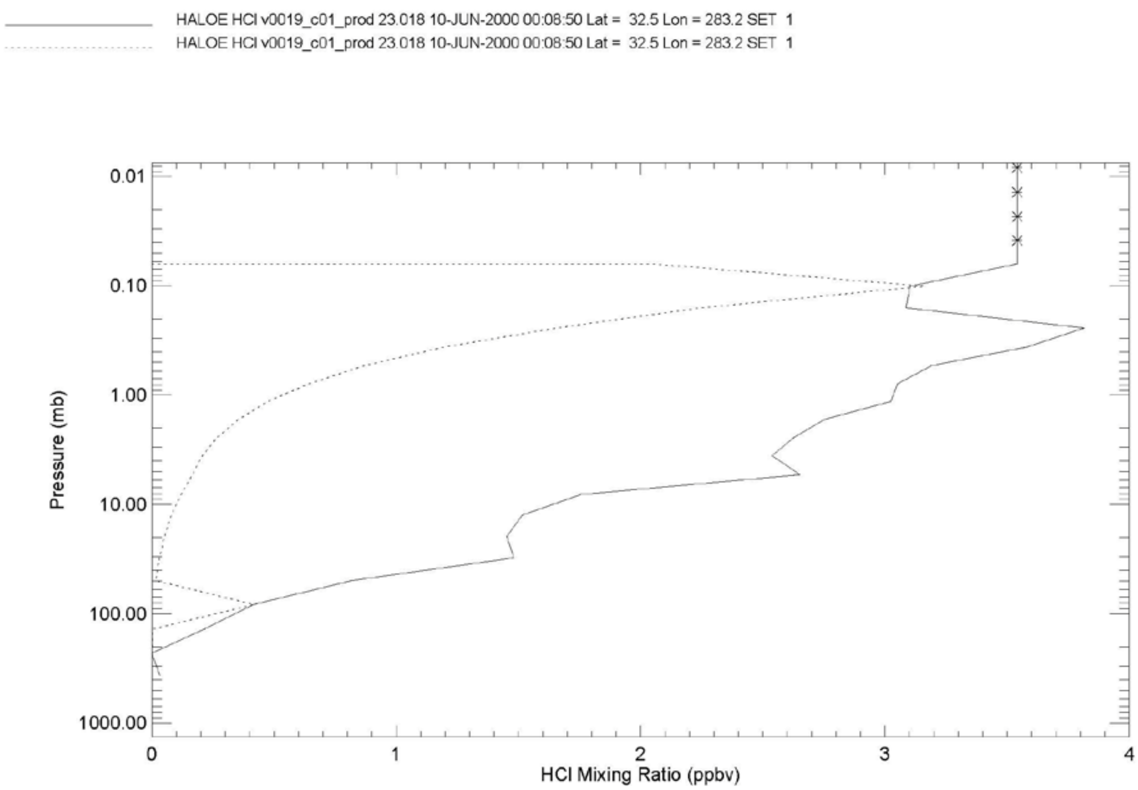
Temperature and temperature precision estimates
June 10, 2000 data



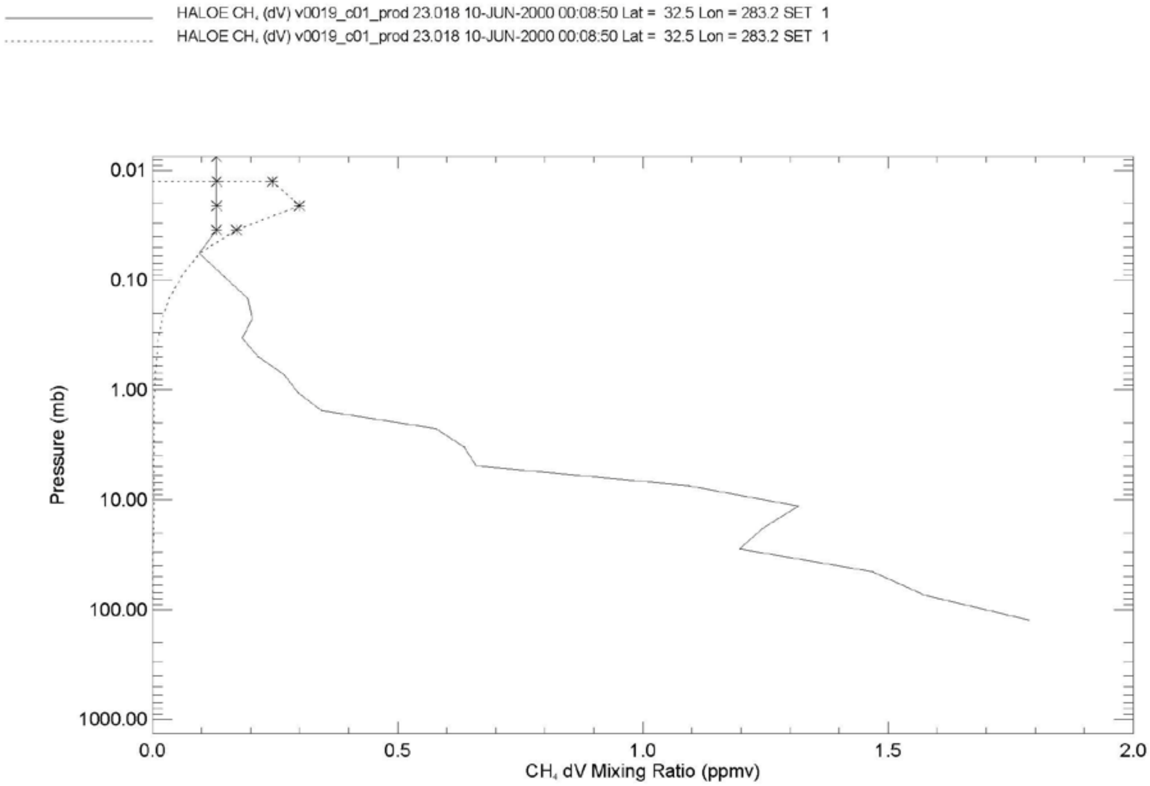


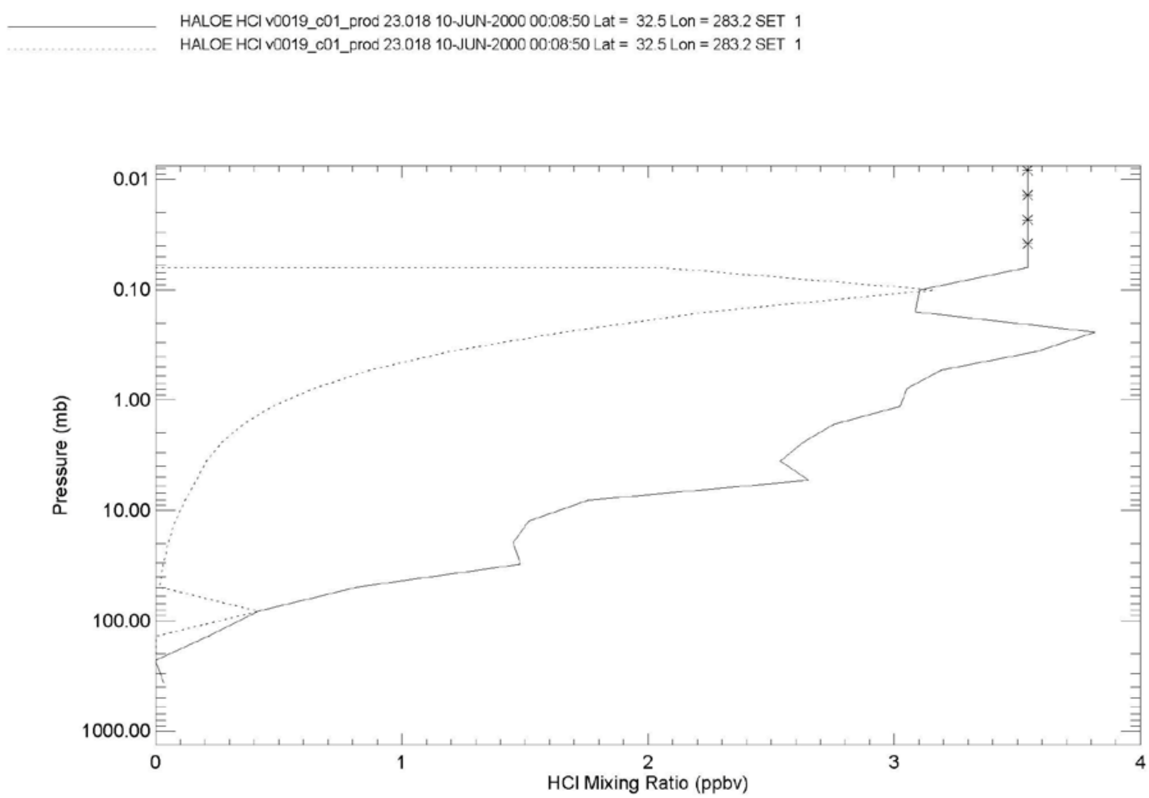
H_2O and NO_2 with precision estimates
June 10, 2000 data



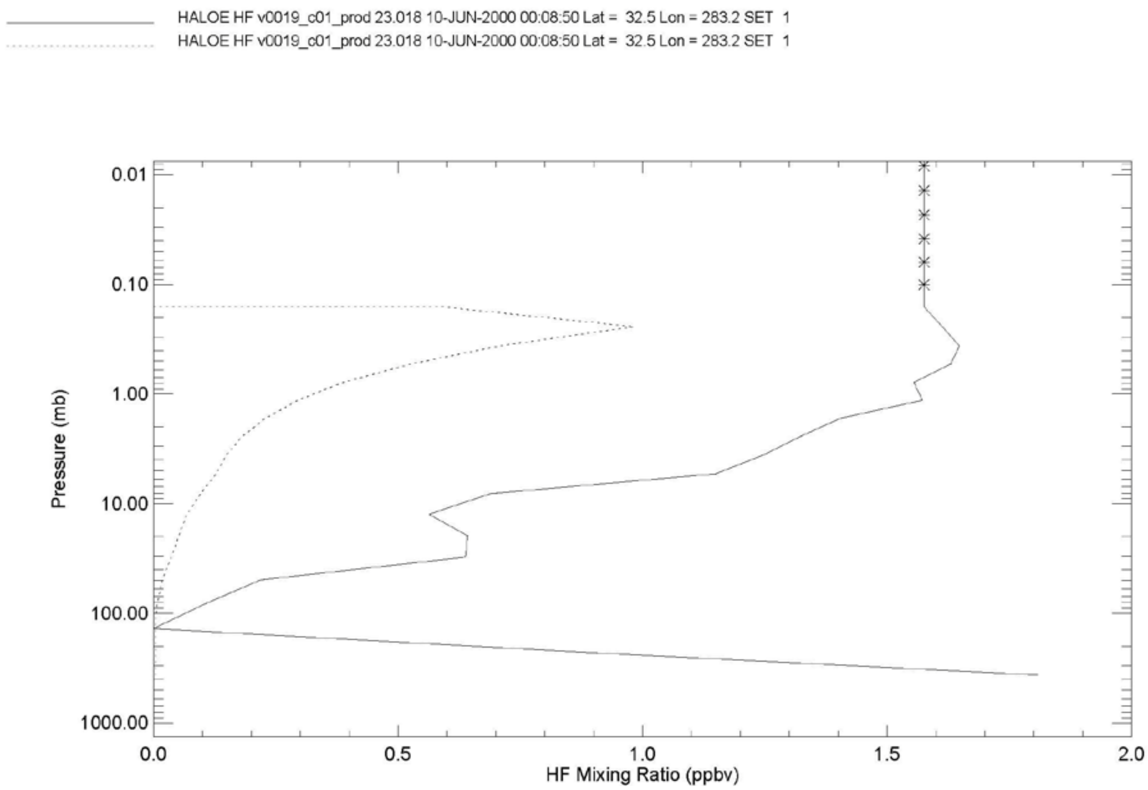


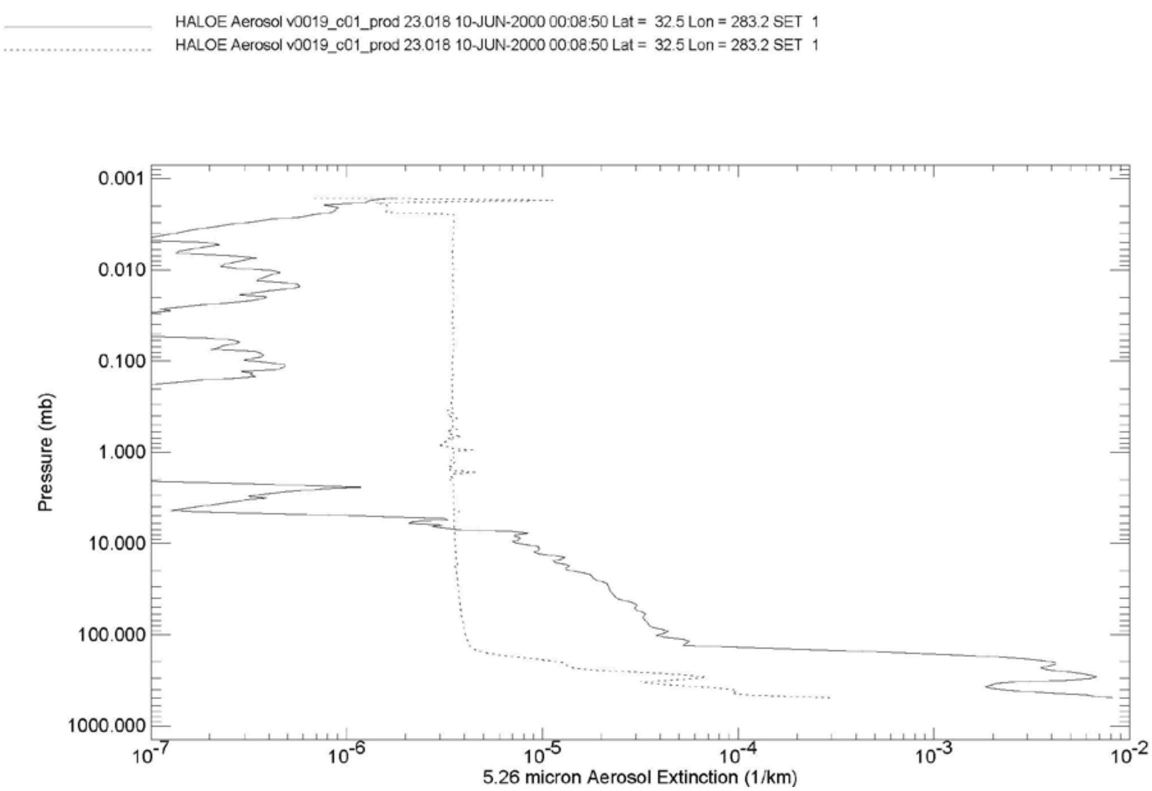
O_3 and NO with precision estimates
June 10, 2000 data



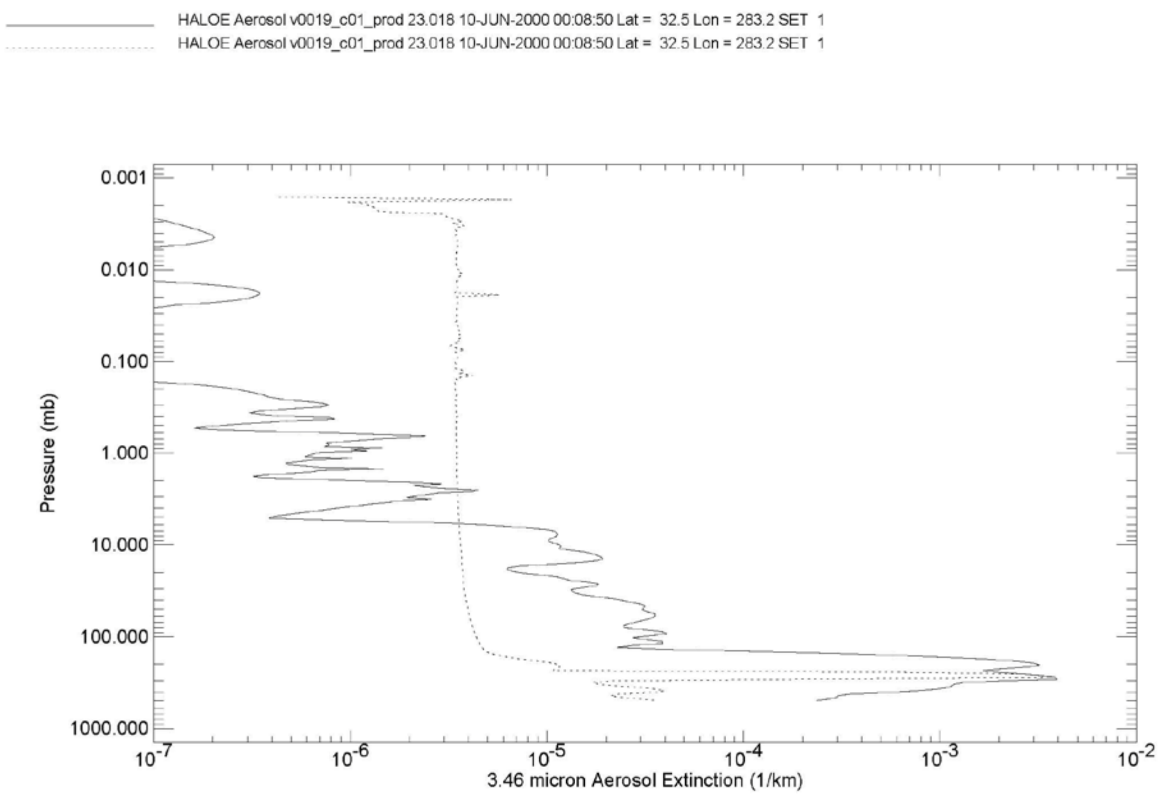


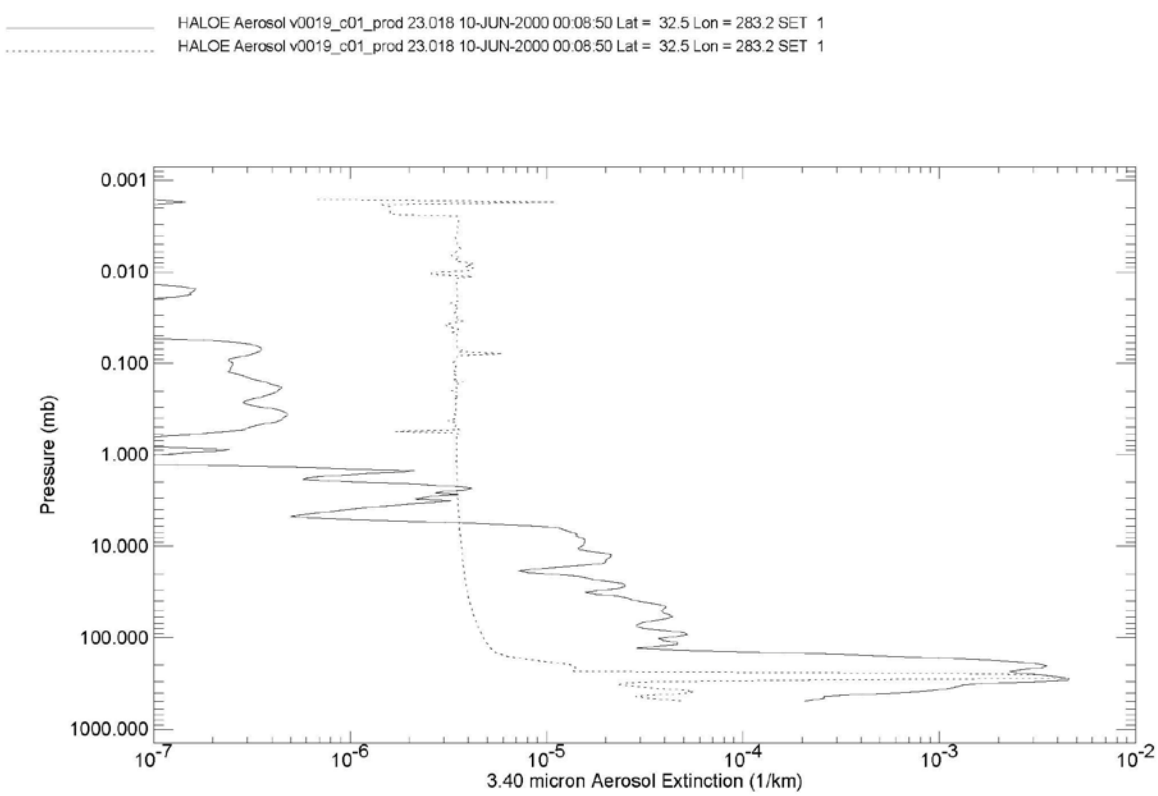
CH_4 and HCl with precision estimates
June 10, 2000 data



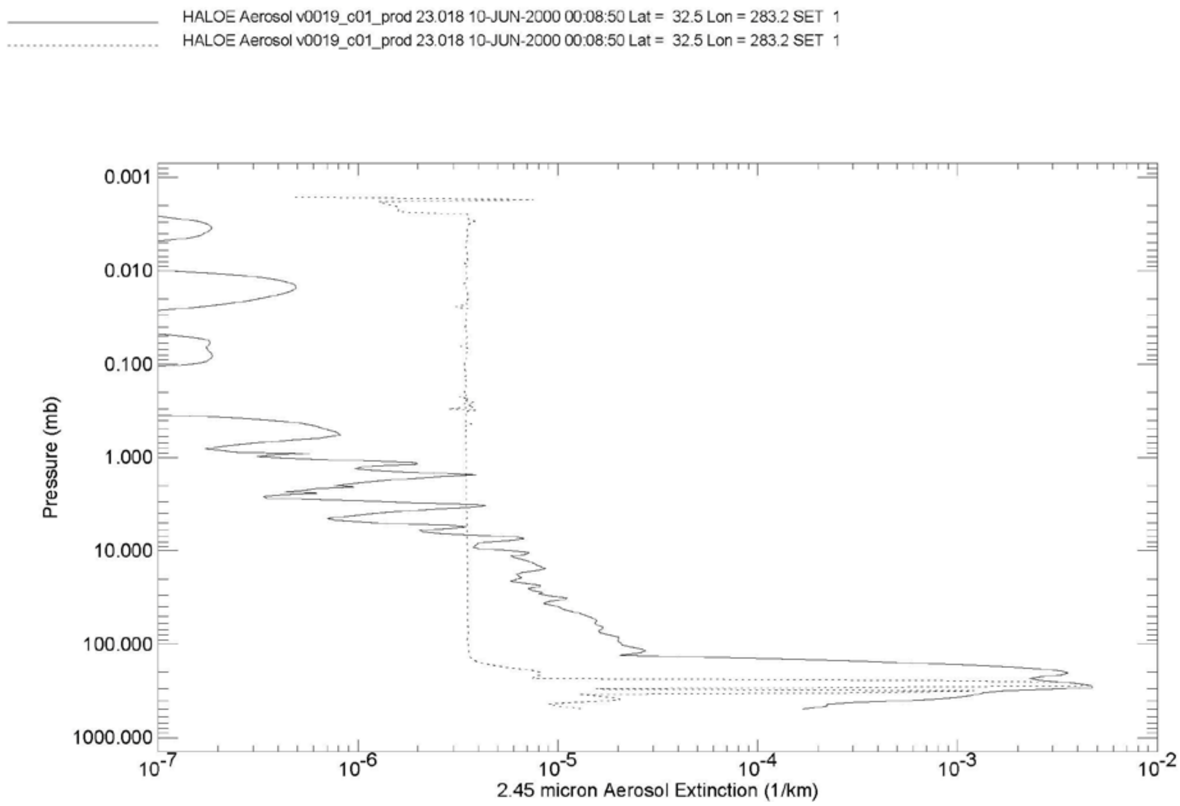


HF and 5.26 micron aerosol with precision estimates
June 10, 2000 data





3.46 and 3.40 micron aerosols with precision estimates
June 10, 2000 data



2.45 micron aerosol with precision estimate
June 10, 2000

Appendix 4: Data Files in Level 2 Run Stream

Files for HALORET (retrieval code) where gray indicates not used in V19. UARS day 5183 is used as an example.

FILE NAME	DESCRIPTION
HALORETSCRT_D5183.DAT	Scratch file
HALORETSIGSCRT_D5183.DAT	Scratch file
CAL_SHALOE_L2.XCONTROL_V0019_C03_PROD	Control file
HALOE_L2_SQC_D5183.DAT	Quality file
DBSCRT_D5183.DAT	Database scratch file
CAL_SHALOE.XNONO01_V0019_C01_PROD	NO database for NO V
CAL_SHALOE.XNOO301_V0018_C01_PROD	O_3 database for NO V
CAL_SHALOE.XNOH2O01_V0019_C01_PROD	NO-H_2O overlap database for NO V
CAL_SHALOE.XNOH2OOV_V0019_C01_PROD	H_2O database for NO V
CAL_SHALOE.XNON2O01_V0019_C01_PROD	N_2O database for NO V
CAL_SHALOE.XNO_H2OCO2OV_V0019_C02_PROD	H_2O-CO_2 overlap database for NO V
CAL_SHALOE.XNOCO201_V0019_C01_PROD	CO_2 database for NO V
CAL_SHALOE.XCO2CO201_V0018_C05_PROD;	CO_2 database for CO_2 Ch.
CAL_SHALOE.XCO2H2O01_V0018_C01_PROD	H_2O database for CO_2 Ch.
CAL_SHALOE.XCO2N2O01_V0018_C01_PROD	N_2O database for CO_2 Ch.
CAL_SHALOE.XCO2H2OOV_V0018_C01_PROD	CO_2-H_2O overlap database for CO_2 Channel
CAL_SHALOE.XH2OCH401_V0015_C01_PROD	CH_4 database for H_2O Channel
CAL_SHALOE.XH2OO201_V0015_C01_PROD	O_2 continuum database for CO_2 Ch.
CAL_SHALOE.XH2OH2O01_V0015_C01_PROD	H_2O database for H_2O Channel
CAL_SHALOE.XH2OCH4OV_V0015_C01_PROD	H_2O-CH_4 overlap database for H_2O Channel
CAL_SHALOE.XNO2CH401_V0015_C01_PROD	CH_4 database for NO_2 Ch.
CAL_SHALOE.XNO2O201_V0015_C01_PROD	O_2 continuum database for NO_2 Ch.
CAL_SHALOE.XNO2H2O01_V0015_C01_PROD	H_2O database for NO_2 CH.
CAL_SHALOE.XNO2NO201_V0015_C01_PROD	NO_2 database for NO_2 Ch.
CAL_SHALOE.XNO2H2OOV_V0015_C01_PROD	NO_2-H_2O overlap database for NO_2 Channel
CAL_SHALOE.XO3O301_V0015_C01_PROD	O_3 database for O_3 Channel
CAL_SHALOE.XO3H2O01_V0015_C01_PROD	H_2O database for O_3 Channel
CAL_SHALOE.XO3CO201_V0015_C01_PROD	CO_2 database for O_3 Channel
CAL_SHALOE.XO3N2O01_V0015_C01_PROD	N_2O database for O_3 Ch.
CAL_SHALOE.XO3H2OOV_V0015_C01_PROD	O_3-H_2O overlap database for O_3 Channel.
CAL_SHALOE.XHCLHCLA1_V0019_C01_PROD	HCl database for HCl V
CAL_SHALOE.XHCLCH4A1_V0019_C02_PROD	CH_4 database for HCl V
CAL_SHALOE.XHCLO3A1_V0019_C01_PROD	O_3 database for HCl V

CAL_SHALOE.XHCLH2OA1_V0019_C01_PROD	H_2O database for HCl V
CAL_SHALOE.XHCL_CH4H2OOV_V0019_C01_PROD	HCl-CH_4 overlap database for HCl V
CAL_SHALOE.XCH4CH401_V0015_C01_PROD	CH_4 database for CH_4 V
CAL_SHALOE.XCH4H2O01_V0015_C01_PROD	H_2O database for CH_4 V
CAL_SHALOE.XCH4HCL01_V0015_C01_PROD	HCl database for CH_4 V
CAL_SHALOE.XCH4H2OOV_V0015_C01_PROD	CH_4-H_2O overlap database for CH_4 V
CAL_SHALOE.XCH4NO201_V0015_C01_PROD	NO_2 database for CH_4 V
CAL_SHALOE.XHFCO2A1_V0019_C01_PROD	CO_2 database for HF V
CAL_SHALOE.XHFCH4A1_V0019_C01_PROD	CH_4 database for HF V
CAL_SHALOE.XHFH2OA1_V0019_C01_PROD;	H_2O database for HF V
CAL_SHALOE.XHF_H2OCH4OV_V0019_C01_PROD	HF-CH_4 overlap for HF V
CAL_SHALOE_L2.XDIGRADLIB_V0015_C01_PROD	Diurnal gradient database
CAL_SHALOE_L2.XMIXLIB2_V0016_C03_PROD	Climatology mixing ratios
HALORETOUT_D5183.DAT	Retrieved profiles
HALOE_L1_SFINAL_D5183.V0019_C01_RAC	Level 1 file
CAL_SHALOE_L2.XCHANNELINFO_V0019_C01_PROD	Line-by-line control file
CAL_SHALOE_L2.XANO_V0015_C01_PROD	Spectral line file for NO DV
CAL_SHALOE_L2.XACH4_V0019_C01_PROD	Spectral line file for CH_4 DV
CAL_SHALOE_L2.XAHCL_V0019_C01_PROD	Spectral line file for HCl DV
CAL_SHALOE_L2.XAHF_V0019_C01_PROD	Spectral line file for HF DV
CAL_SHALOE_L2.XANOGC_V0015_C01_PROD	Spectral parameters for NO gas cell
CAL_SHALOE_L2.XACH4GC_V0019_C01_PROD	Spectral parameters for CH_4 gas cell
CAL_SHALOE_L2.XAHCLGC_V0015_C01_PROD	Spectral parameters for HCl gas cell
CAL_SHALOE_L2.XAHFGC_V0015_C01_PROD	Spectral parameters for HF gas cell
CAL_SHALOE_L2.XFNO_V0015_C01_PROD	Spectral filter for NO Ch.
CAL_SHALOE_L2.XFCH4_V0018_C01_PROD	Spectral filter for CH_4 Ch.
CAL_SHALOE_L2.XFHCL_V0015_C01_PROD	Spectral filter for HCl Ch.
CAL_SHALOE_L2.XFHF_V0015_C01_PROD	Spectral filter for HF Ch.
FILTER_D5183.DAT	Scratch file for filter Calculations
CAL_SHALOE_L2.XACO2_V0009_C02_PROD	Spectral line file for CO_2 V
CAL_SHALOE_L2.XAH2O_V0009_C02_PROD	Spectral line file for H_2O V
CAL_SHALOE_L2.XANO2_V0009_C02_PROD	Spectral line file for NO_2 V
CAL_SHALOE_L2.XAO3_V0009_C02_PROD	Spectral line file for O_3 V
CAL_SHALOE_L2.XFCO2_V0009_C02_PROD	Spectral filter for CO_2 V
CAL_SHALOE_L2.XFH2O_V0009_C02_PROD	Spectral filter for HF V
CAL_SHALOE_L2.XFNO2_V0009_C02_PROD	Spectral filter for NO_2
CAL_SHALOE_L2.XFO3_V0009_C02_PROD	Spectral filter for O_3 V
CAL_SHALOE_L2.XHVY_MOLEC_V0019_C01_PROD	Heavy molecule file
CAL_SHALOE_L2.XTIPS_COEF_V0019_C01_PROD	Total Internal Partition Sums File
CAL_SHALOE_L2.XCH4MIXEDSETS_V0019_C01_PROD	Line mixing parameters for CH_4 DV

Files for CNDNS2D (forms Level 2 final product)

FILE NAME	DESCRIPTION
HALOE_L2_SFINAL_D5183.V0019_C01_RAC	Level 2 file name
HALOE_L1_SFINAL_D5183.V0019_C01_RAC	Level 1 file name
HALOE_L2_SQC_D5183.DAT	Quality file
CAL_SHALOE_L2.XSOLVER_V0019_C01_PROD	Used in calculating some aerosol items
HALORETOUT_D5183.DAT	Retrieved profiles

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14. ABSTRACT
The Halogen Occultation Experiment (HALOE) on the Upper Atmosphere Research Satellite (UARS) provided high quality measurements of key middle atmosphere constituents, aerosol characteristics, and temperature for 14 years (1991-2005). This report is an outline of the Level 2 retrieval algorithms, and it also describes the great care that was taken in characterizing the instrument prior to launch and throughout its mission life. It represents an historical record of the techniques used to analyze the data and of the steps that must be considered for the development of a similar experiment for future satellite missions.

15. SUBJECT TERMS
HALOE; Retrieval algorithms; Satellite experiment

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