PREPARED BY: REICHLE

DATE: 4/11/94

LEVEL 1 VALIDATION

- VALIDATE FORWARD RADIATIVE TRANSFER BY COMPARISON WITH WIDELY ACCEPTED MODELS (EXPLOIT TES STUDIES)

- VALIDATE R.T.M. + CALIBRATION BY USE OF HIGH RESOLUTION GROUND BASED SPECTROSCOPY (NETWORK FOR STRATOSPHERIC CHANGE)

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LEVEL 2 VALIDATION

REGULAR COMPARISONS WITH EXISTING GROUND STATIONS (SEE ATTACHED EXAMPLE)

SOME SURFACE STATIONS WILL BE ABOVE MIXED LAYER, e.g., MAUNA LOA

REGULAR PROGRAM OF STANDARDIZATION & INTERCALIBRATION MUST BE CARRIED OUT

AIRCRAFT CAMPAIGNS WILL BE USED TO CHECK VERTICAL PROFILES USE BOTH DEDICATED AIRCRAFT & AIRCRAFT OF OPPORTUNITY (RESEARCH PROGRAMS) (SEE ATTACHED MAPS LIST)

Upper Atmosphere Research Satellite (UARS)

Microwave Limb Sounder (MLS) Data Validation Plan

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abstract

This is the first draft of the UARS MLS Data Validation Plan. Its format is based on the 'generic' UARS Data Validation Plan outline presented at the February 1990 UARS Science Team Meeting. The 'finalized' version of this document is planned for release following its review and acceptance at the spring 1991 MLS Science Team Meeting.

Release Record

version	*date*	*comments*
0.1	30 January 1990	contents only
0.2	19 October 1990	first draft
0.3	25 October 1990	correction of minor errors in 0.2

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1 Introduction

1.1 Experiment objectives

The objective of the Upper Atmosphere Research Satellite (UARS) Microwave Limb Sounder (MLS) experiment is to perform measurements which, together with those of the other UARS instruments, will provide a data base that can test and extend present understanding of Earth's stratosphere and mesosphere.

The UARS MLS primary measurement objectives are atmospheric profiles of ClO (~15–45 km), O_3 (~15–80 km), H_2O (~15–85 km) and temperature (~20–70 km) along with field-of-view (FOV) tangent pressure (~30–60 km) for a pointing reference. ClO is the dominant form of chlorine which destroys ozone in the stratosphere; its measurement on a global scale has never been performed before, and is essential for understanding and monitoring the depletion of stratospheric ozone by chlorine from industrial products. Measurements of O_3, H_2O and temperature provide additional important information on stratospheric ozone chemistry. The UARS MLS H_2O and O_3 measurements span a larger vertical range than previously explored on a global basis.

Secondary MLS measurement goals include H_2O_2, HNO_3 and one component of wind in the mesosphere. These should be considered as 'research objectives', and it is uncertain at the present time whether they will be of sufficient quality for useful atmospheric studies.

MLS measurements are made by observing millimeter-wavelength spectral line thermal emission as the instrument field-of-view is vertically scanned through the atmospheric limb. All are made simultaneously and continuously, at all times of day and night. See [1] for a description of the technique and additional discussion of the UARS MLS experiment.

1.2 Validation objectives

The objectives of the UARS MLS data validation activities are to produce validated MLS data of demonstrated good quality in the UARS Central Data Handling Facility (CDHF). MLS data to be validated under the plan described here are the primary experiment objectives — profiles of ClO, O_3, H_2O, temperature and pressure. Validation of intermediate data products (*e.g.*, instrument engineering performance and measured radiances) necessary for producing the primary experiment objectives is also covered.

1.3 Validation approach

The validation approach includes

1. Development of appropriate mathematical models,
2. Instrument calibration for determining instrument parameters used in data processing,
3. Error analyses to determine the *expected* errors in the data products,
4. Pre-launch activities which include mathematical simulations and balloon/aircraft measurements to test the techniques and mathematical models
5. Post-launch activities which include
   (a) Routine 'internal consistency' and 'reasonableness' checks,
   (b) Comparison with other 'correlative' (both UARS and non-UARS) measurements

These are described in the following sections of this document. Appendices describe some details of the mathematical models and error analyses.

2 Mathematical models

Mathematical models provide the means for formal error analyses of the MLS data products. There are four mathematical models used for the MLS. These are described in the following subsections

2.1 Instrument model

The 'instrument model' describes the relation between the radiance which is 'input' to the instrument and the counts which are 'output' from the instrument. It consists of the four parts described in the following subsections.

2.1.1 Radiometric response

Radiometric response describes the instrument response to total *absolute* input radiant power. This is the total received power from *all* angular and spectral regions. Appendices A and B give details of this portion of the instrument model.

2.1.2 Spectral response

Spectral response describes the *relative* response of the instrument as a function of frequency. Appendices A and B give details of this portion of the instrument model.

2.1.3 Field-of-view response

Field-of-view response describes the *relative* response of the instrument as a function of angle. Appendices A and C give details of this portion of the instrument model.

2.1.4 Pointing

Pointing describes the UARS MLS field-of-view 'pointing direction'. Appendix C gives details of this portion of the instrument model.

2.2 Atmospheric model

The 'atmospheric model' describes the discrete parameterization of continuous atmospheric variables. There are separate 'models' for the vertical profile representation and the horizontal variation.

2.2.1 Vertical profile representation

Vertical profiles are modeled as a piece-wise linear function of $\log_{10}$(pressure). Volume mixing ratios are used to describe gas abundances. Appendix C gives details.

2.2.2 Horizontal variation

Horizontal variation in the atmosphere *between* 65.536 s MLS 'major frames' (MMAFs) is modeled[1] by a combination of climatology and the retrieved profile from the previous MMAF. Appendix E describes details. Horizontal variation *within* the region covered by an MMAF is assumed to be zero.[2]

2.3 Radiance model

The 'radiance model' describes the modeled radiance signals which are measured by the MLS instrument. This includes a model of the atmospheric radiative transfer and the relevant spectroscopic data base.

2.3.1 Radiative transfer

Appendix C gives details of the radiative transfer model.

2.3.2 Spectroscopic data base

Appendix D describes this data base.

[1]This 'modeling' of the horizontal variation between MMAFs occurs *only* in the generation *a priori* profiles for the retrieval algorithm.

[2]We plan, at some later date, to investigate the sensitivity of our results to horizontal gradients and, if necessary correct for any significant effects. Because MLS retrievals are from 'optically-thin' spectral regions these effects are expected to be very small.

2.4 Retrieval model

The 'retrieval model' describes the method by which atmospheric parameters are 'retrieved' from the measured radiances. The sequential estimation technique, whose principles are described by Rodgers in chapter 7 of [2], is used. Appendix E gives details of this model.

3 Instrument Calibration

Instrument calibration is separated into the same four categories as the instrument model described in §2. These are described briefly in the following subsections The MLS Calibration Report [3] now being prepared describes the instrument calibration in detail.

3.1 Radiometric calibration

Radiometric calibration determines the instrument response to total input radiant power received from *all* angular and spectral regions. Properties of the MLS on-board radiometric calibration target are precisely determined prior to launch. This target, and 'cold space', are observed at least once per minute in orbit to provide continuous radiometric calibration of the instrument. Appendix B is a preliminary report on the UARS MLS radiometric calibration.

3.2 Spectral calibration

Spectral calibration determines the *relative* response of the instrument as a function of frequency. This is achieved by end-to-end swept-frequency measurements on each MLS spectral channel through the complete radiometer system and multiplexing optics. Subsystem measurements are also performed for consistency checks. Sufficient measurements are also performed through the complete antenna system to ensure that its spectral performance is adequate.

3.3 Field-of-view calibration

Field-of-view calibration determines the *relative* response of the instrument as a function of frequency. This is achieved by measurements of the end-to-end angular response of the instrument for each radiometer in the instrument. The measurements are performed on a precision antenna range, and with enough sampling in angle to achieve the accuracy requirements.

3.4 Pointing calibration

Pointing calibration determines the UARS MLS field-of-view 'pointing direction'. This is performed as part of the 'field-of-view' calibration, and amounts to precision measurement of the FOV direction (for each of the three MLS radiometers) relative to the instrument alignment cube.[3]

[3] Note, however, that the 'registration' of retrieved MLS profiles to UARS pressure surfaces is achieved by the MLS pressure measurements. MLS pointing calibration (together with the UARS attitude control system) assures that the instrument FOV direction is placed in an adequate direction for obtaining the necessary atmospheric measurements.

4 Error analyses

The objective of error analyses is to determine the *expected* errors in atmosphric profiles retrieved from MLS data. These errors can be both 'systematic' and 'random'. 'Systematic' errors are, at least to first order, independent of time; they usually represent a constant error in the 'zero' or 'scaling' of the results. 'Random' errors are time-varying; they must be described by some statistical parameter such as the expected standard deviation in the error; a ubiquitous source of random error is instrument noise. Rodgers [4] has developed general techniques to characterize errors in atmospheric profiles retrieved from remote sounding measurements. We intend to eventually apply Rodgers' techniques to our measurements.

4.1 Spectroscopic Data Base

Appendix F gives an analysis of systematic errors expected from uncertainties in the MLS spectroscopic data base. This analysis is for the effect of this error source on the MLS measurements of O_3, which has the most stringent requirement for absolute accuracy of measurements.

4.2 Calculated Radiance

Appendix F gives an analysis of errors expected from uncertainties in radiative transfer calculations. This analysis is for the effect of this error source on the MLS measurements of O_3, which has the most stringent requirement for absolute accuracy of measurements.

4.3 Instrument Calibration

Appendix F gives an analysis of errors expected from instrument calibration. This analysis is for the effect of this error source on the MLS measurements of O_3, which has the most stringent requirement for absolute accuracy of measurements. The analysis is separated into the effects of uncertainties due to 'field-of-view', 'radiometric', and 'spectral' calibration.

4.4 Atmospheric Model

The 'atmospheric model' can introduce errors if it does not adequately represent the atmosphere. Our current atmospheric model, for example, represents vertical profiles as piece-wise linear which is a crude (but probably adequate) approximation to nature.

4.5 Retrieval Algorithm

Errors, both systematic and random, due to the retrieval algorithms are determined by end-to-end simulations. Some of these simulations are described in §5.

5 Pre-launch activities

5.1 Instrument calibration

A major pre-launch activity is calibration of the MLS flight instrument. This has been completed successfully and is documented in the MLS Calibration Report [3] now in preparation. Appendix B gives an intermediate document describing *radiometric* calibration.

5.2 Balloon and aircraft measurements

All spectral lines measured by UARS MLS have been, or will be, measured by instruments operating on balloon or aircraft platforms. This gives assurances that the expected signals occur in the atmosphere at the expected levels, and that they are free of spectral interference.

5.2.1 Balloon 205 GHz Measurements

The Balloon Microwave Limb Sounder (BMLS) instrument measures the same 205 GHz spectral lines of ClO and O_3 that are measured by UARS MLS. The instrument has made 13 flights, all successful, since its initial flight in 1980.[4] See [5, 6, 7] for published results from the BMLS flights. During recent flights the BMLS instrument has been flown with filter bank subsystems which are functionally identical to those on UARS MLS.

5.2.2 Balloon 63 GHz Measurements

A 63 GHz subsystem was developed under the UARS MLS program for use on the BMLS. That subsystem has been completed, except for the spectrometer which is now under construction. It will be integrated with the 205 GHz BMLS instrument in spring 1990 for a first flight planned for fall 1991. The objective of the BMLS 63 GHz measurements is to test the radiative transfer model at a very precise level. This test is needed for obtaining and vali-

[4]An additional 'flight' was attempted during which the balloon failed during ascent through the tropopause; the BMLS instrument was parachuted to ground, recovered safely and flown successfully within approximately two weeks.

dating pressure measurements to the inherent precision of the UARS MLS experiment.[5]

5.2.3 Aircraft 183 GHz measurements

The 183 GHz H_2O and O_3 lines measured by UARS MLS have been measured by the early aircraft MLS instrument [8, 9]. These aircraft measurements have verified the expected level of these signals in the atmosphere, and that they are free of spectral interference.

5.3 Tests with flight instrument data

Data from the UARS MLS flight instrument are used to test the Level 1 Data Processing programs. These tests demonstrate the adequacy of this software for converting Level 0 counts to radiances, and for producing the engineering outputs needed for monitoring instrument performance. The initial version of the Level 1 Production Processing Software is used in the flight instrument ground support equipment (GSE) for routine monitoring of the flight instrument performance.

5.4 Intercomparison of calculated radiances

Tests of the 'forward model' have been performed by an 'intercomparison campaign' of calculated radiances using (mostly) independent software and algorithms, and separate scientific personnel. The comparison was between results from MLS groups at JPL and Edinburgh University and acceptable agreement (within 1%) was obtained. Separate comparisons were made of:

1. Monochromatic ray radiances,

2. Radiances averaged by the MLS spectral response,

3. Radiances averaged by the MLS field-of-view and spectral response.

[5]Coupled with 'external' information on the height of pressure surfaces, such as in the NMC data sets to be available during production processing on the CDHF, the MLS pressure measurements can (and will) be used to help validate the UARS observatory pointing.

5.5 Simulation tests

Simulation tests are performed on all levels of data processing. This tests both the algorithms and the software. Data at all levels are produced as part of this activity. Results of each processing Level are compared with the (simulated) 'truth' as a test for 'closure'. Simulated radiances calculated from simulated Level 2 atmospheric data are used to produce a simulated Level 0 data set. The production Level 1 software creates a 'production' Level 1 data set which is compared to the 'input' simulated radiances. The production Level 1 data set is processed through the Level 2 production software to produce a 'production' Level 2 data set which is compared to the original 'simulated' data.

Figure 1 shows a.. example of a simulation test for a single vertical profile of H_2O. Figure 2 shows results of O_3 retrievals at a fixed UARS pressure surface along the measurement tangent track. Figure 3 shows residuals (retrieved values minus 'truth') along the tangent track of this simulation.

An early product of the simulation activity is the MLS Simulated Instrument Data Set (SIDS) provided to the UARS project for testing programs on the CDHF. Three days of data were produced for the SIDS. The first day had no simulated instrument noise. The second day had simulated noise. The third day had 'actual' instument noise (but with some simulations required).

A major pre-launch activity will be full-up rehearsal of data processing (using Version 3.0 of our production software to be delivered in January 1991) and analyses activities. This is planned to cover continuously at least a two 'UARS month' (two UARS yaw states) period. The simulated atmospheric data will be from the model of W.L. Grose (UARS Theoretical Investigation PI). Data processing operations, certain validation activities, analyses tools, routine hard copy output and personnel will be exercised as part of this rehearsal. One day's data will be processed each day. This rehearsal will simulate, as far as possible, all the post-launch validation activities described in §6.

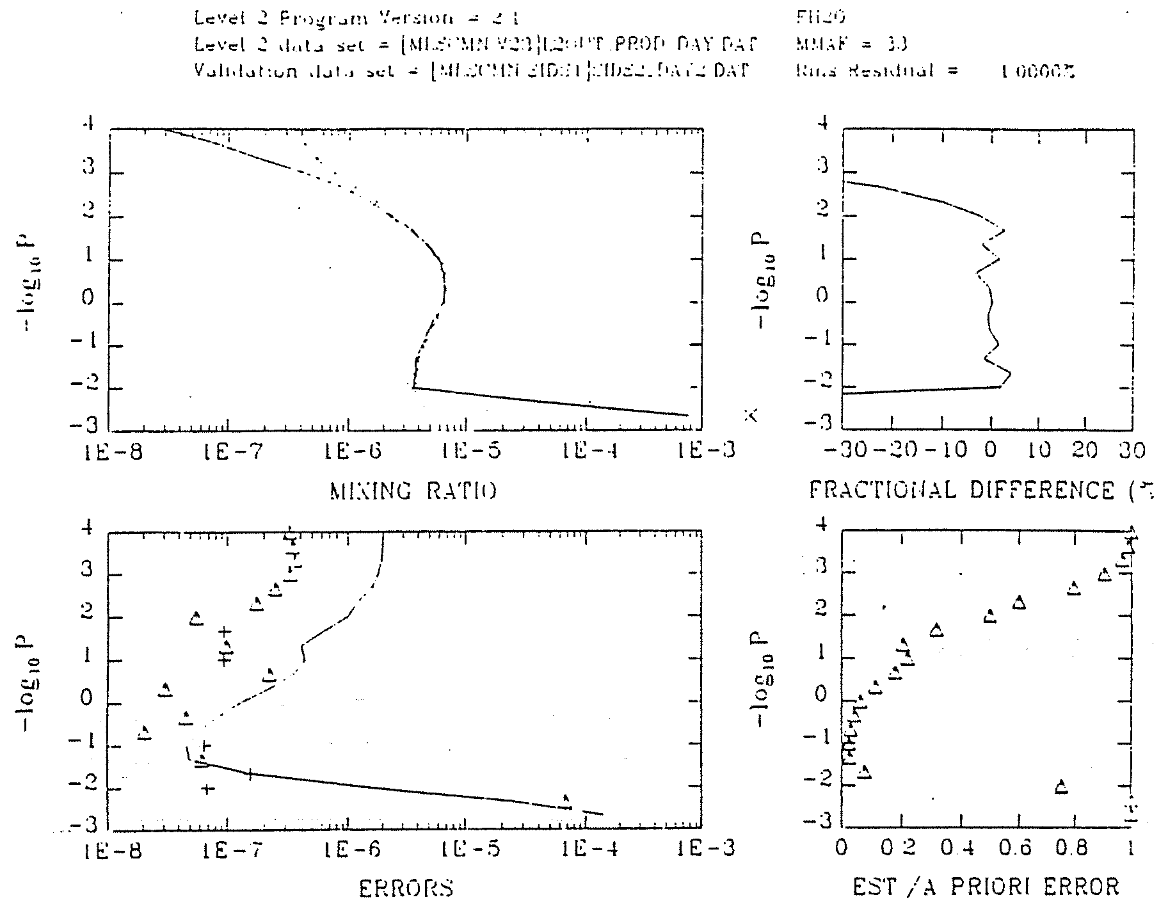


Figure 1: Results of simulated profile retrievals for H_2O. The upper left panel shows the profile — the continuous curve is the retrieved profile; crosses are 'truth'; the retrieved profile deviates from truth at high altitudes because of lack of signal, and at low altitudes because of attenuation by excessive H_2O absorption (the spectral lines become 'saturated'). The upper right panel shows the percentage difference between the retrieval and truth. The bottom left panel shows errors — the continuous curve gives the formal error predicted by the retrieval algorithm and symbols show actual errors for this particular retrieval (+ indicates positive errors, Δ indicates negative errors); the actual errors are lower than the formal errors because this retrieval had no simulated instrument noise (in order to determine errors introduced *solely* by the retrieval algorithm). The lower right panel gives the ratio of the estimated formal retrieval error to the assumed a priori error in the profile; a significant increase in this ratio (>~0.4, say) indicates a significant decrease in the amount of information provided by the MLS measurements.

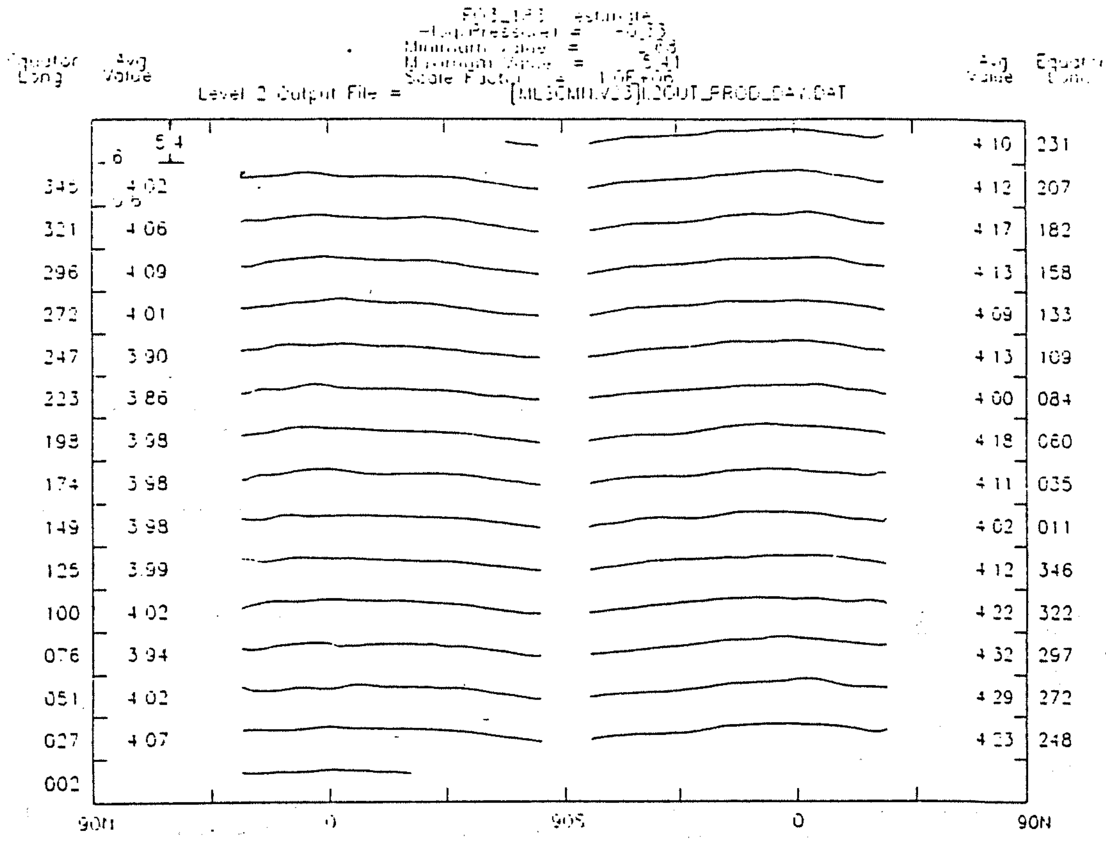


Figure 2: Results of simulated O_3 retrievals from the MLS 183 GHz band. Radiances for these simulations were calculated using atmospheric model data of W.L. Grose for one day in the month of February. The results shown here are for O_3 along the MLS tangent track on UARS pressure surface 16 (2.1 mb, ~42 km) with UARS in a 'south-looking' yaw state. The horizontal axis is latitude of the tangent track. Curves from separate orbits are displaced in the vertical; the 'break' in the middle of the curve occurs because the tangent track reaches no further south than 80°. The descending ('night)' side of the orbit is to the left of this break; the ascending ('day') side is to the right. The longitude of the equator crossing of the day and night sides of the orbit are given by the vertically spaced numbers outside the box. The average value of O_3 (in parts per million volume mixing ratio) along the tangent track for the separate day and night sides of each orbit are given by the vertically spaced numbers inside the box. The '5.4' scale mark near the upper left corner gives the scale on which the curves are plotted: each curve is plotted on the same vertical scale covering the range 0.6–6.0 in parts per million of O_3.

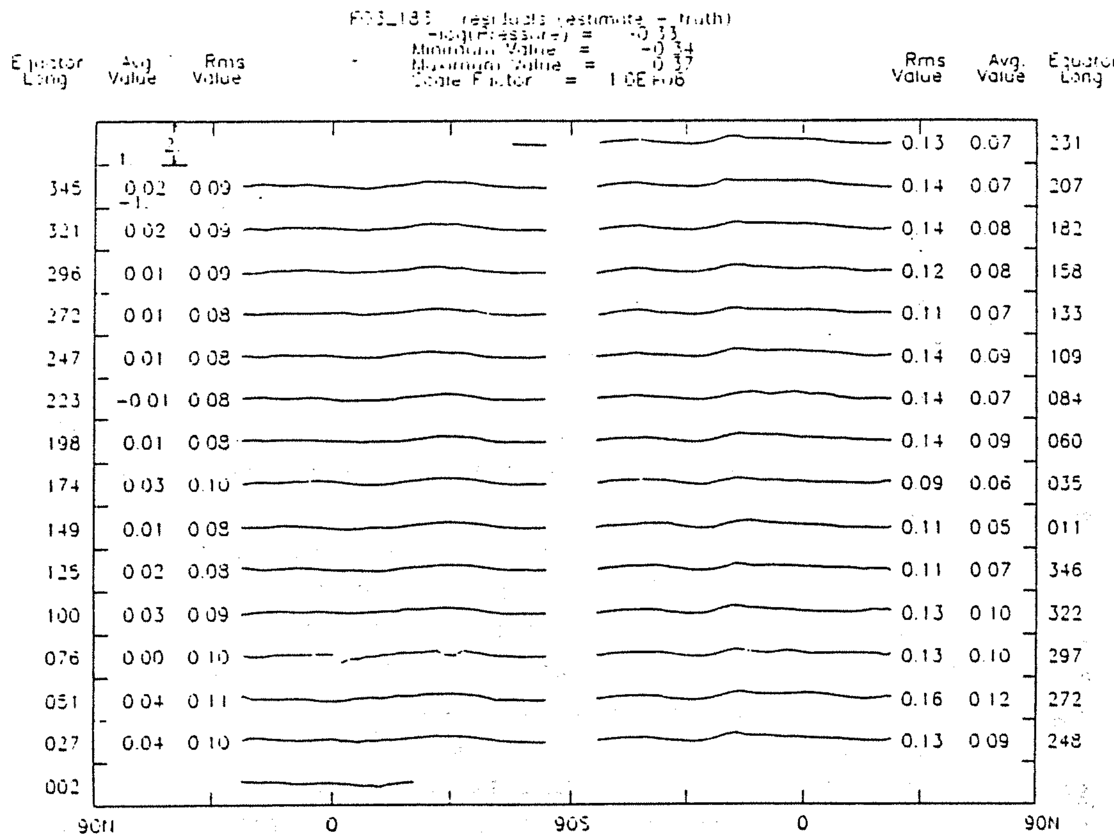


Figure 3: Residuals along the tangent track. The format is the same as in the previous figure, except that the curves are for the difference between 'retrieved' O_3 and 'true' O_3. The two columns of vertically spaced numbers inside the box give the rms and average values for the difference for the separate day and night sides of each orbit.

6 Post-launch activities

6.1 Instrument activation and engineering validation

The MLS instrument will be activated as soon as possible after UARS is safely in orbit.

During activation, *all* MLS engineering data will be examined to ensure the instrument is functioning adequately from an 'engineering' point-of-view. The MLS will also be exercised with an appropriate set of commands. The activation will occur over a time period of approximately one week, and is described in the MLS In-Orbit Activation Plan [10].

6.2 Initial instrument performance validation

6.2.1 Radiometric Performance

Following engineering validation, approximately 3 days will be devoted to validation of the instrument radiometric performance.

The instrument switching mirror will be programmed to look only at 'target' and 'space', with occasional measurements of the radiometric 'zero'. These data will be processed through the MLS Level 1 Production Processing software at the UARS CDHF.

The MLS Level 1 Diagnostics File will be examined to validate the radiometer noise temperatures, gains and stability. These data will also be used to determine (or verify previous plans for) the 'operational' switching mirror sequence to be used for calibration, and the parameters for the 'optimal' algorithm in the Level 1 processing radiance calibration.

These data will also be processed through the Level 1 Production program using program 'overrides' (user input parameters) to make the program treat selected space and target views as 'limb' data which are calibrated radiometrically. These data (which contain no 'atmospheric signal') will be examined to validate the expected noise level in the calibrated radiances.

6.2.2 Pointing Placement

Following radiometric performance validation, approximately two days will be devoted to validating pointing placement.

The measured atmospheric radiance 'curves of growth' will be used to validate pointing placement. These will be known adequately from calculations, since an accuracy of only ~3 km is needed for placement. The tentative sequence of events is as follows (the switching mirror is held fixed on 'limb' for these tests, and the instrument Level 0 data is examined):

1. The UARS 'oblateness' command will be disabled and the instrument scan programmed to cover tangent heights from approximately -70 km to +130 km in ~30 equal steps during each MMAF. This range assures that the atmospheric radiance curve of growth will be scanned each MMAF throughout the orbit. This will be done for at least one orbit. The FOV angle corresponding to ~30 km tangent height will be determined by comparing the measured 63 GHz radiance curve of growth with the pre-calculated curve.

2. Step 1 will be repeated but, if necessary, an offset will be added to the scan program to center it at ~30 km tangent height. The data from this orbit will be examined to ensure that the scan has been centered at ~30 km. If not, the appropriate corrections will be made and this test repeated.

3. Step 2 will be repeated, but with the UARS 'oblateness' correction implemented in the MLS scan program. The data will be examined to ensure that the oblateness correction is performing properly.

4. Step 3 will be repeated, but using the 'nominal' MLS scan pattern. The resulting curves of growth will be examined to make sure this scan pattern produces radiance 'curves of growth' which are consistent with that expected from this scan pattern.

6.2.3 Spectral Baseline Performance

Following initial validation of pointing placement, approximately 7 days will be devoted to validating the spectral baseline[6] performance of the instrument. Data will be processed through the Level 1 Processing software on the CDHF,

[6]'Spectral baseline' is the spectral radiance output from the instrument for *no* input atmospheric radiance.

and the Level 1 Radiance file will be examined with analyses tools on the MLS RAC at JPL. The 6 days for this validation are budgeted as follows:

1. The MLS instrument will be operated in its 'nominal' operating mode, except that the FOV scan pattern will have a 3° upward offset and the UARS 'oblateness' correction will be disabled. This puts the FOV direction at the 'bottom' of the scan at 145 km tangent height, so that no atmospheric signal is present in any portion of the scan. After Level 1 processing the spectral radiance for each band will be examined (with appropriate averaging) to determine the instrument spectral baseline.

2. Same as previous, but with the 'oblateness' correction enabled.

3. Same as previous, but with a 1.5° upward offset in the FOV scan pattern. This puts the 'bottom' of the scan at 85 km tangent height where there will be negligible atmospheric signal for most channels. This test determines if the spectral baseline changes when the scan angle is changed by the scan range required for the atmosphere. A contingency plan will be prepared for implementation if there is a change in the baseline.

4. Repeat of day 2.

5. Repeat of day 3.

6. Contingency.

We expect to have an automated program to create a file of spectral baseline 'offsets' to be used in Level 2 Processing if these tests indicate they are needed.

6.2.4 Radiometric Calibration

Following the spectral baseline performance validation, the 'reasonableness' of the instrument radiometric calibration will be examined. Approximately two days' data will be examined for this purpose (the same data set will also be used for initial FOV and spectral performance validation).

This involves comparison of *absolute* values of measured radiance with calculated radiance. This comparison is done in situations where the radiance is from *optically-thick* atmospheric paths, and from locations where atmospheric conditions are relatively well-known. The choices of these locations are based on climatology. It is expected that the tropics, where temperature and pressure are relatively stable, will be used for the 63 GHz radiometer. The upper stratosphere (tropics?) is expected to be used for the 183 GHz radiometer. The troposphere must be used for the 205 GHz radiometer, as the stratosphere is never optically thick in any of its channels. A very rough estimate of the 'climatological' uncertainty for these tests is $\sim$2% for 63 GHz, $\sim$5% for 183 GHz, and $\sim$20% for 205 GHz. More work will be done prior to launch on selection of the best regions for these tests, and estimation of the uncertainties.

6.2.5 Field-of-view

The same data set used for initial validation of the instrument radiometric calibration will be used for initial validation of the FOV performance. Channels and scan angles in which the atmospheric signal has its 'curve of growth' will be examined for field-of-view performance. Here we examine the shape of the radiance 'curve-of-growth' as a function of scan angle, and compare it with pre-calculated curves for atmospheric stable regions. These regions might likely be the same as discussed above for radiometric calibration evaluation. They will be defined prior to launch.

6.2.6 Spectral Performance

This will use the same data set as for 'radiometric' and 'field-of-view' validation. The process will be similar to that for FOV validation, but will examine radiances as a function of spectral channel.

6.3 Long-term instrument perfomance validation

The above activities will be repeated routinely throughout the mission as validation of instrument performance. A later revision of this document will discuss long-term instrument performance validation in more detail. It will also discuss, for example, how we plan to use UARS 'special events', such as observatory 'roll-up', for instrument performance validation.

6.4 Level 1 data validation

Level 1 data will be validated by (1) checking for 'reasonable' values, (2) examination of the residuals between measured radiances and those calculated from the MLS Level 2 product, and (3) comparison with independent radiance measurement.

6.4.1 'Reasonableness' tests

The first level of 'reasonableness' is simply checking that the radiances do not exceed, by more than the amount expected from instrument noise, the range which is physically possible. This corresponds to the range of thermal emission from black bodies having temperatures between $\sim$3 K and $\sim$320 K. The Level 1 processing software will automatically perform this check, and set a flag in the Level 1 output file when the criterion is not met.

A second level is determination of whether the measured radiances have 'reasonable' variation from channel-to-channel (*e.g.*, spectral emission lines should appear where expected) and with tangent height (the radiances should show 'curves of growth' as the FOV is scanned downward through the atmospheric limb).

A third level is determination of whether the measured radiances are within the range expected from 'climatology'. The degree to which this test can be trusted depends upon the accuracy of the climatology. Relatively good climatology exists for some parameters (*e.g.*, temperature, O_3) measured by MLS, but essentially none for other parameters (*e.g.*, ClO). We will routinely compare MLS radiances with those computed from climatology (and, where, climatology does not exist, from models). This will be done as part of the same process of examining the radiance residuals which is described in the following subsection. The 'UARS climatology' being assembled by R. Seals and colleagues will be used. Even where 'good' climatology is expected to exist, however, we must be careful not to rely upon it completely (remember the TOMS experience with the Antarctic ozone hole). The decision on whether discrepancies with climatology indicate 'invalid' data, or whether they indicate unexpected atmospheric phenomena will be done by the MLS Science Team, *not* by computer.

6.4.2 Radiance residual tests

A necessary condition for the MLS retrieval process is that the radiances calculated from the retrieved Level 2 product agree with the measured radiances within the expected noise. The residuals between calculated and measured radiances will be examined routinely for each day's data set. Residuals larger than expected from instrument noise indicate a systematic 'error' of some sort. The 'error' could either be in the measured radiances, in the retrieved Level 2 product, or in the forward model which calculates the radiances. The 'form' of the residuals, *i.e.*, how they vary with scan angle, spectral channel, time, location, *etc.*, should indicate which is the likely source of error.

Radiances will be calculated for each day's data set from the Level 2 product transferred from the CDHF to the MLS RAC. These will be compared with the measured radiances. A flag will be set (in the output file produced as part of this validation process) when the difference exceeds a certain amount (say 4× the expected standard deviation). Routine hard copy output will also be produced which shows, with appropriate 'binning': (1) the measured radiances compared with the range expected from climatology, and (2) the residuals between the measured radiances and those calculated from the Level 2 product. Table 1 gives specifications for the hard copy output planned to be routinely produced for this aspect of radiance validation. Figure 4 gives an example of the format of this output.

6.4.3 Radiance intercomparisons

The measured MLS radiances will, where possible and appropriate, be compared with other measurements. The Balloon Microwave Limb Sounder (BMLS), which will perform measurements as part of the UARS Correlative Measurements Program, will provide comparative measurements of the 205 and 63 GHz radiances. The Microwave Atmospheric Sounder (MAS) experiment on the Shuttle Atmospheric Laboratory for Applications and Science (ATLAS) measures the same 183 GHz H_2O spectral line as the UARS MLS; we will explore a collaborative effort with the MAS team. It must be remembered, however, that the different instruments can have very different spectral and field-of-view characteristics, and care must be taken to ensure that the radiance intercomparisons are useful.

Table 1: Specification of the routine hard copy output for Level 1 radiance validation.

Data Level	*Pages per Day*	*Product Name*	*description*
1	90	Measured Spectra	Plots of measured Limb Radiances *vs.* channel number (1–15) for each of the six MLS bands. All six bands will be plotted on one page in a format similar to that now produced by GSE analyses software. Plots will be produced separately for ascending and descending ('day' and 'night' sides of the orbit and will be averages over the day's data set for the latitude and tangent pressure ranges given in the table below. Each plotted point will have a vertical 'error bar' which encompasses the maximum and minimum values which went into the average. The 'error bar' will have a 'tick' indicating the ± one standard deviation in radiance expected from instrument noise. An envelope will also be plotted showing the envelope radiances expected from climatology (or theoretical model) for these ranges of latitude and pressure.
		Residual Spectra	Same as 'Measured Spectra' except that quantity plotted is the difference beween the measured radiances and the radiances calculated from the Level 2 output data file. Each plotted point will have a vertical 'error bar' which encompasses the maximum and minimum differences which went into the average. The 'Residual Spectra' will be plotted on the same page as the 'Measured Spectra'.

latitude† *range*
> +70
+50 to +70
+20 to +50
−20 to +20
< −20

tangent pressure range	~ *height range*
< 0.0015 mb	>90 km
0.05 – 0.0015 mb	70 - 90 km
0.2 – 0.05 mb	60 - 70 km
1. – 0.2 mb	50 - 60 km
3. – 1. mb	40 - 50 km
10. – 3. mb	30 - 40 km
50. – 10. mb	20 - 30 km
200. – 50. mb	12 - 20 km
>200 mb	<12 km

† A positive latitude indicates the hemisphere favored by the day's UARS yaw state.

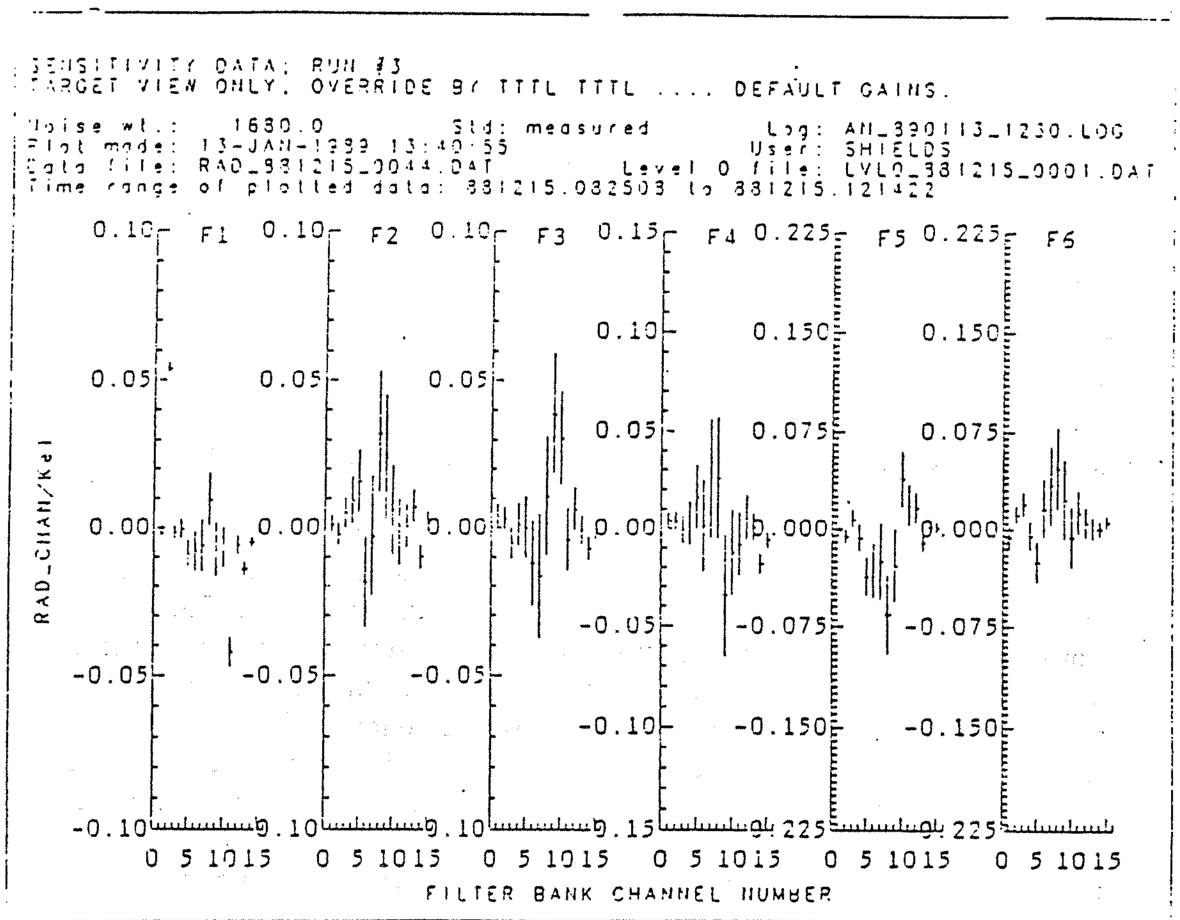


Figure 4: Example of routine hard copy output for examining Level 1 radiances. This example is actual output from GSE software used for validating the MLS flight instrument performance during ground tests. The six panels show the radiance from each of the six MLS spectral bands. The post-launch data validation output will have *two* areas per page, each similar to that shown here. The top area will have the measured radiances and the envelope expected from climatology; the bottom area will have the residuals from that calculated using the Level 2 product.

6.5 Level 2 data validation

Level 2 data will be validated by checking for 'reasonable' values and, where possible, by comparison with independent measurements. Selected individual profiles and zonal averages from each day's data set will be routinely examined. Column ozone obtained by integrating the MLS Level 2 profile will also be compared to column ozone measured by stations in the ground-based Dobson network.

6.5.1 Individual profiles

Individual profiles from selected 'locations' around the globe will be examined each day. These locations are chosen to span a range of latitudes and, where possible, be near a ground-based site making routine observations. Table 2 gives a tentative choice for the locations, and the format of the routine hardcopy output to be produced.

Our initial choice is for six locations at 'high' latitudes which are reached in only one hemisphere for a given UARS yaw state, and for nine locations at 'low' latitudes which are reached on both UARS yaw states. These locations include Dobson stations, ground-based measurement sites, and balloon launch sites. Although comparative measurements will not be available at all times from these sites, our team will check individual MLS profiles from these locations each day. This provides a 'spot check' on the reasonableness of the profile, and gives us experience on the amount of atmospheric variation at these locations based on MLS results. Knowledge of this variation will be useful for understanding how much of any discrepancy might be due to atmospheric variability (since the MLS and comparative measurements will certainly not be for exactly the same time, space and 'measurement volume').

Each output page will contain four panels which show vertical profiles of O_3, H_2O, ClO and temperature. There will be a separate page for the ascending and descending ('day' and 'night') sides of the orbit. The profile will be selected by (1) first choosing the orbit which has a tangent track nearest in longitude to the location coordinates, then (2) by choosing the latitude along the tangent track which is nearest. These pages will be filed in a binder for later comparison with any measurements which can be obtained from the chosen locations.

6.5.2 Average Profiles

Profiles averaged around zonal bands will be routinely examined for each day's data. The output format will be the same as that for the 'individual' profiles described above, but the 'error bars' on each averaged profile will show the range of values and the standard deviation of data which went into the average. This will identify any 'wild' profiles, since the averages encompass the *full* day's data set. Table 3 gives specifications for the routine hardcopy output to be produced.

6.5.3 Column Ozone

A file will be produced containing values of column ozone from the MLS Level 2 data for all MLS measurements which are made at locations within approximately 300 km of selected Dobson stations. The Dobson measurements of column ozone, when they become available, will be compared with MLS data from this file.

Table 2: Specification of the routine hardcopy output for Level 2 'individual profiles'.

Data Level	*Product Name*	*Pages per Day*	*description*
2	Individual Profiles	30	Plots of individual profiles from the Level 2 Output file. One page will contain four panels with each panel giving the profile for one of the quantities listed below. The vertical coordinate for the plots is $-\log_{10}$(pressure/mb).

quantity	*units*
ClO	ppbv
O_3†	ppmv
H_2O	ppmv
temperature	kelvins

†Separate 205 and 183 GHz O_3 profiles.

Plots will be produced for the ascending and descending ('day' and 'night') tangent track and latitude nearest to the locations listed below. Each plotted profile point will have a horizontal 'error bar' which is ± the estimated uncertainty for this point given in the Level 2 Output file. The header of the plot will contain the time, latitude and longitude of the profile from the Level 2 data set; it will also contain the differences in latitude and longitude between the Level 2 profile point and the locations given below. The ozone panel will also contain the column ozone (in Dobson units) obtained from integrating the Level 2 profile.

Locations for individual profiles (tentative)

latitude	longitude	name	comment
77.3 N	69.3 W	Thule, Greenland	
58.5 N	94.0 W	Churchill, Canada	Dobson station
52.4 N	4.1 W	Aberystwyth, Wales	Dobson station
48.? N	10.5 E	Hohenpeissenberg, Germany	Dobson station
45.? N	5.? E	Haute Provence, France	ground site
40.1 N	105.3 W	Boulder, Colorado	Dobson station
34.5 N	104.3 W	Ft. Sumner, NM	balloon launch site
34.3 N	117.7 W	Table Mountain, California	ground site
31.7 N	95.6 W	Palestine, Texas	balloon launch site
19.5 N	155.6 W	Mauna Loa, Hawaii	ground site
13.1 N	80.2 E	Madras, India	
3.1 N	101.4 E	Kuala Lumpur, Malaysia	
0.1 S	78.3 W	Quito, Ecuador	
12.2 S	130.4 E	Darwin, Australia	
TBD S			
38.? S	145.? E	Melbourne, Australia	Dobson Station (?)
43.3 S	172.4 E	Christchurch, New Zealand	
TBD S			
TBD S			
78.? S	167.? E	McMurdo, Antarctica	ground site
76.? S	27.? W	Halley Bay, Antarctica	Dobson station

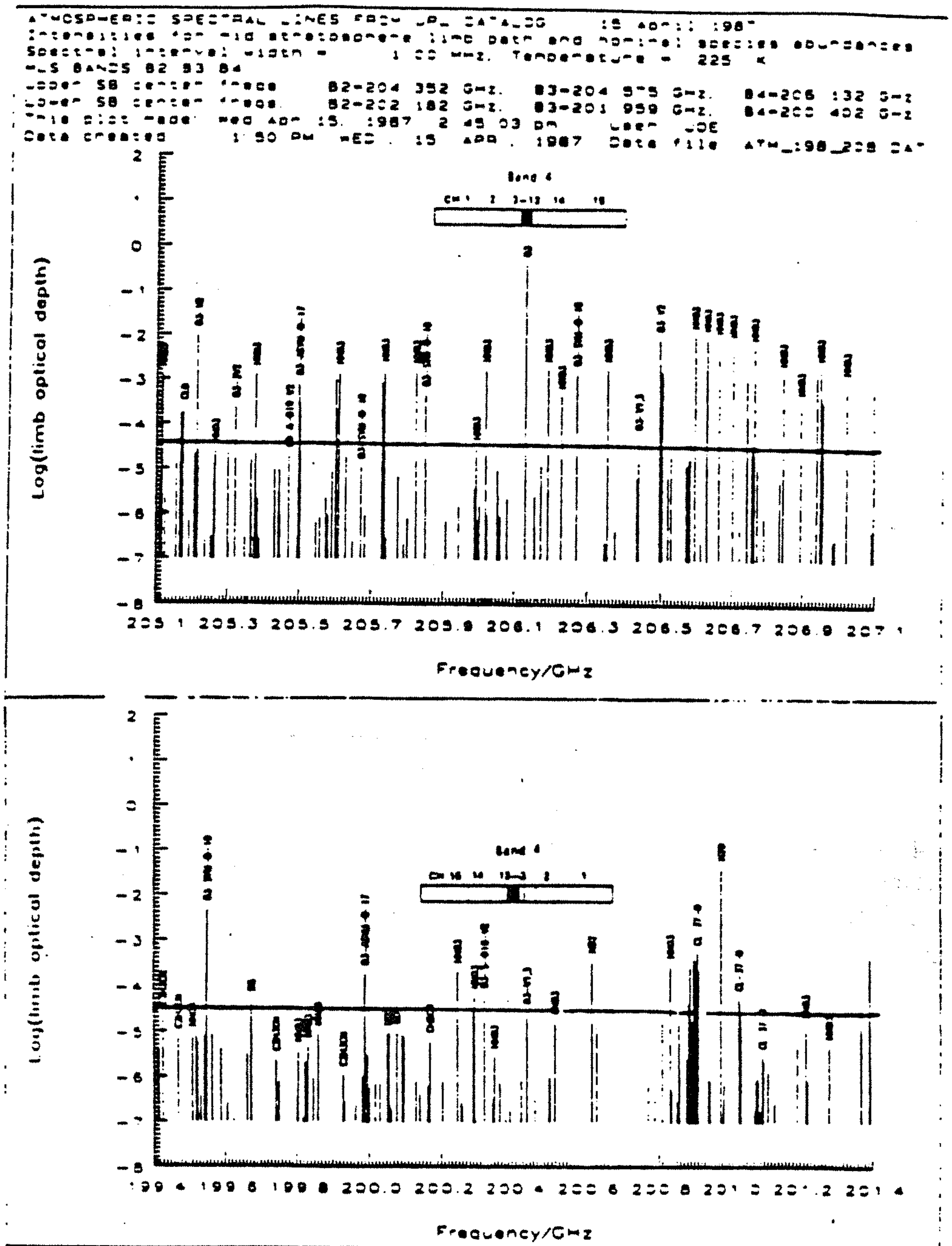


Figure A.3: Band 4 Spectral Lines

In addition to the species whose lines are shown in *fig. A.3*, band 4 will be affected by emission from both liquid and gaseous H_2O in the troposphere.

A.4 Bands 5 and 6

The objectives of MLS bands 5 and 6 are to measure stratospheric and mesospheric H_2O and O_3. Spectral lines in and near these bands are shown in *fig. A.4*. As can be seen these bands are completely dominated by the strong H_2O and O_3 lines. All other lines are expected to be weaker by at least a factor of about 1000 and thus negligible.

Table A.5 summarizes the species which are expected to affect bands 5 and 6.

Table A.5: Species which affect bands 5 and 6

Species	Altitude Range [*km*]
H_2O	5 - 90
O_3	10 - 80

Liquid H_2O in the troposphere may also affect these bands but more quantitative calculations are needed to determine whether this is significant due to the large optical depth of the H_2O and O_3 lines which will greatly attenuate the liquid emission.

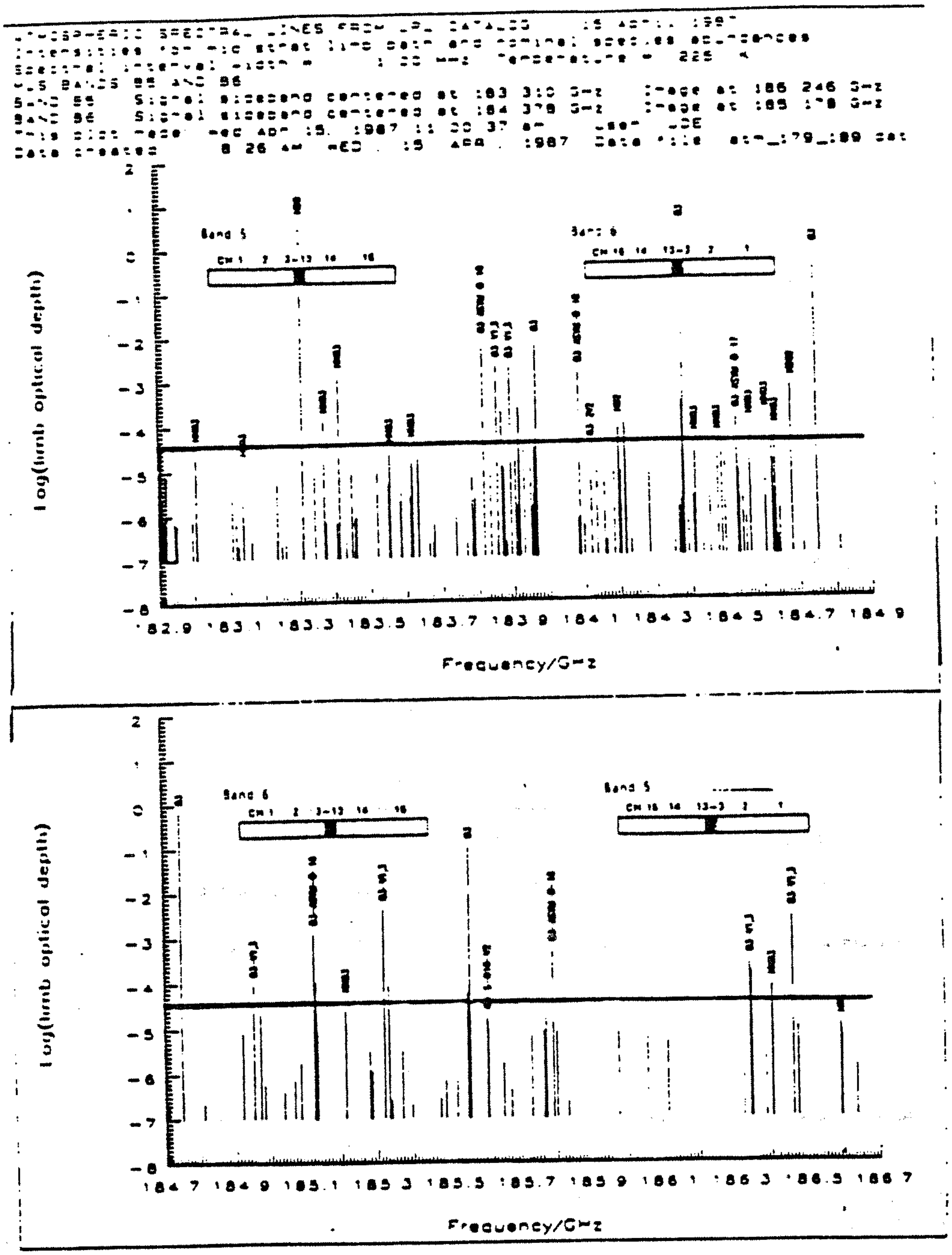


Figure A.4: Bands 5 & 6 Spectral Lines

A.5 Summary

Table A.6 summarizes the atmospheric species which are expected to affect the MLS measurements and the altitude range over which effects are expected.

Table A.6: Summary of species expected to affect the MLS measurements

Species	Altitude Range [*km*]
O_2†	5 – 80
O_3	10 – 80
H_2O	5 – 90
$C\ell O$	20 – 50
....	....
HNO_3	15 – 40
H_2O_2	20 – 40
^{18}OOO	15 – 50
$O^{18}OO$	15 – 50
HO_2	35 – 60
SO_2‡	15 – 40
H_2O^{liq}	5 – 15

The species above the dotted line are the primary objectives.

† O_2 is used to obtain a pressure level to which other measurements can be referred.

‡ SO_2 is expected to have an effect only after a major volcanic eruption.

A.6 Spectral Lines over 10 *GHz* Interval

Fig. A.5, *fig. A.6*, and *fig. A.7* show spectral lines from the JPL catalog [14] over a 10 *GHz* frequency range centered near the positions of the MLS bands. The format is the same as used before with the vertical scale being the logarithm of the optical depth for an observation path passing through the middle stratosphere and the species abundances given in *table A.1*.

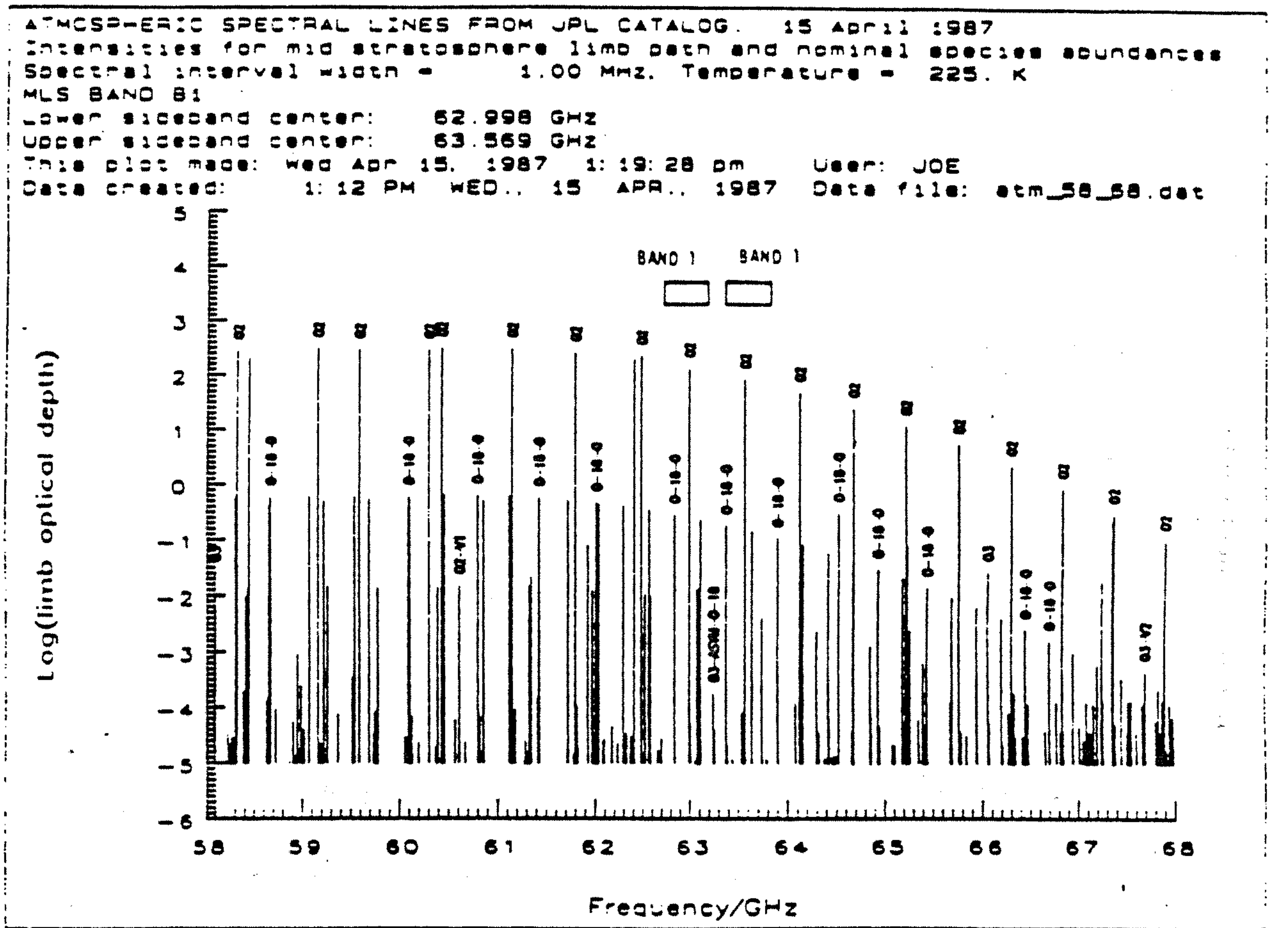


Figure A.5: Spectral Lines in 10 GHz Region around Band 1

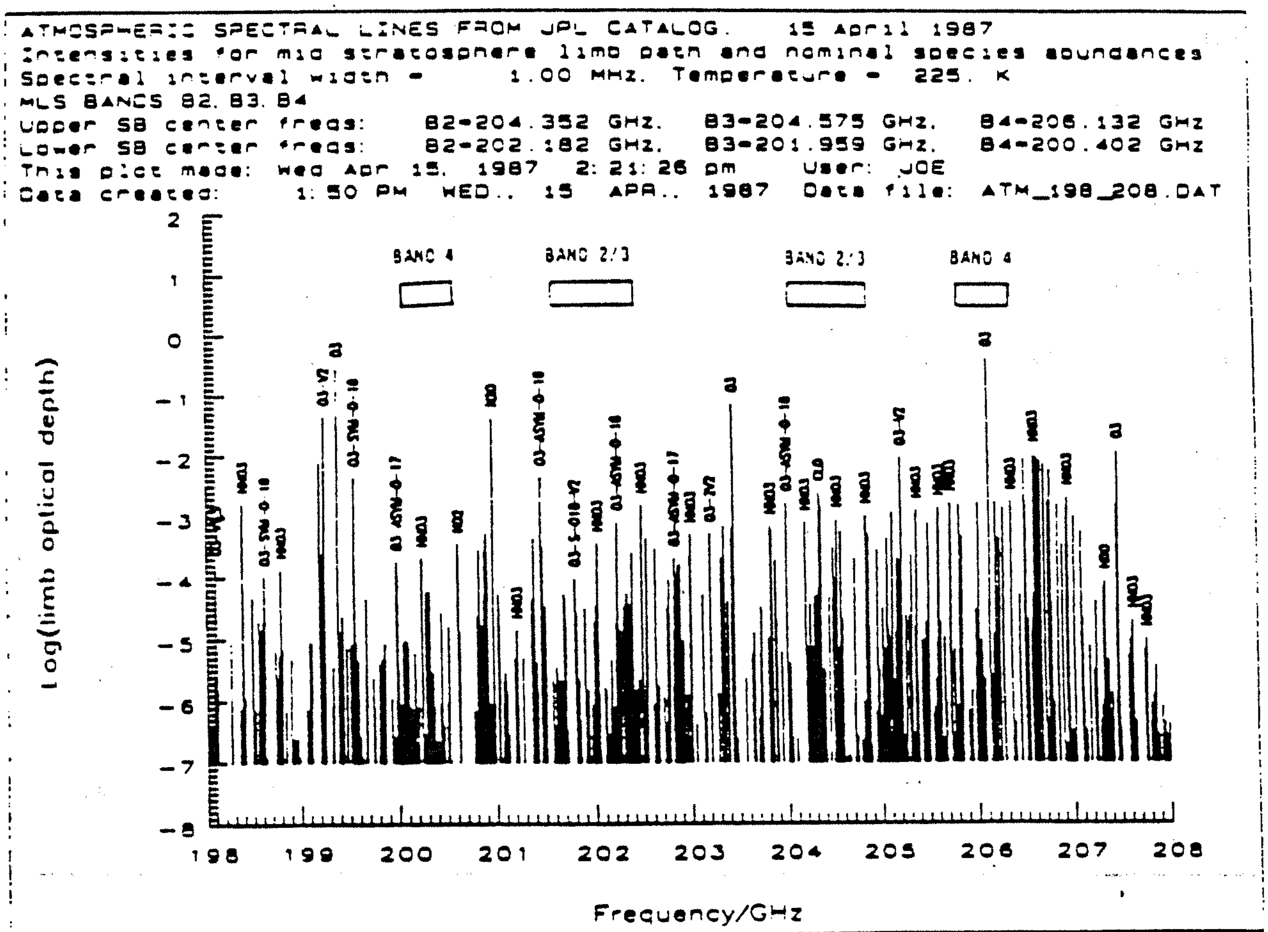


Figure A.6: Spectral Lines in 10 GHz Region around Bands 2, 3 & 4

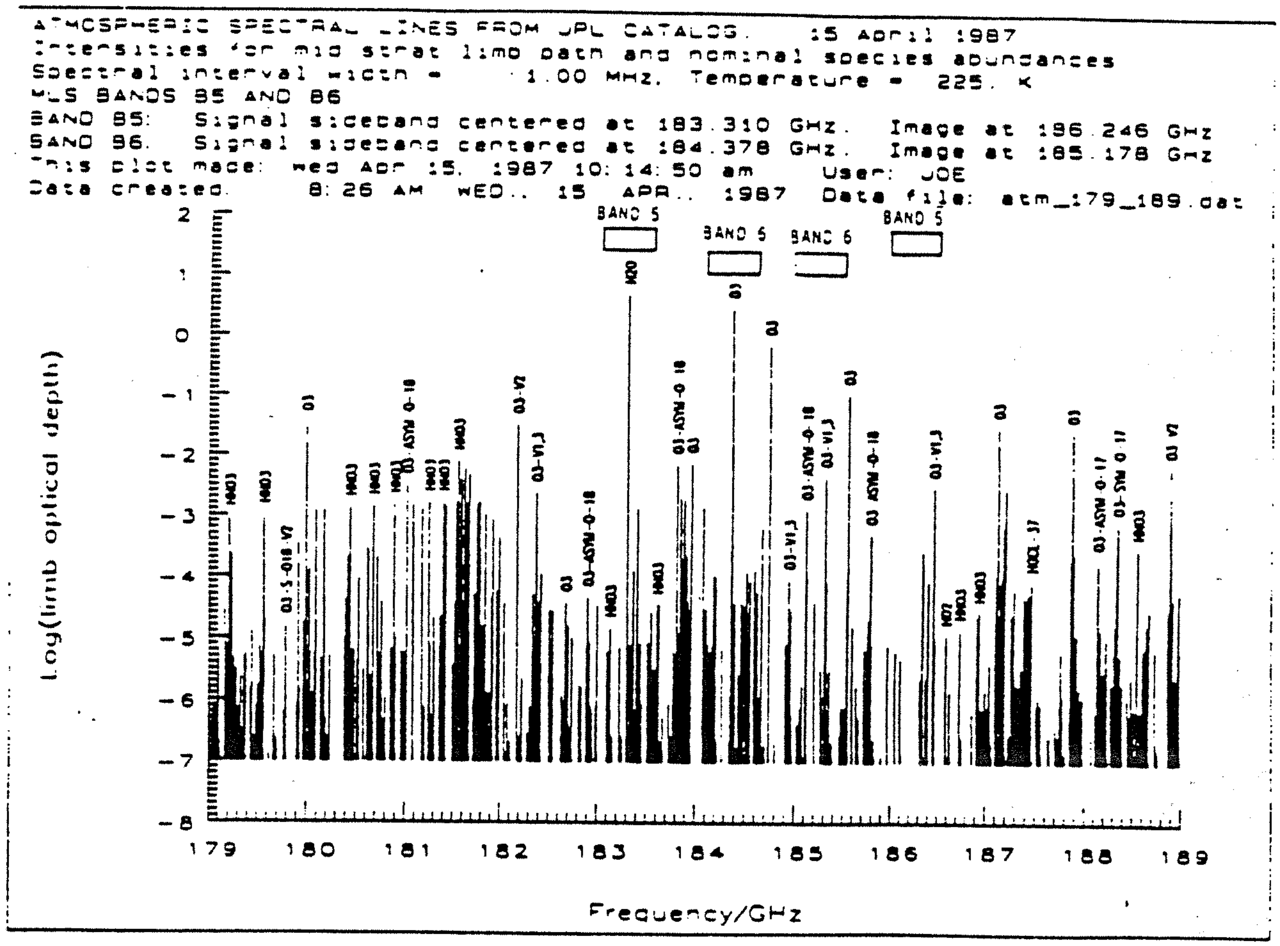


Figure A.7: Spectral Lines in 10 GHz Region around Bands 5 & 6

Appendix B

Theory of Sequential Estimation

This section summarizes the theory of retrievals using sequential estimation. This retrieval technique, first discussed in the context of remote sensing of the atmosphere by Rodgers [16] (see also Chapter 7 of [9]), has been used successfully for the NIMBUS 7 Stratospheric and Mesospheric Sounder (SAMS) experiment [6].

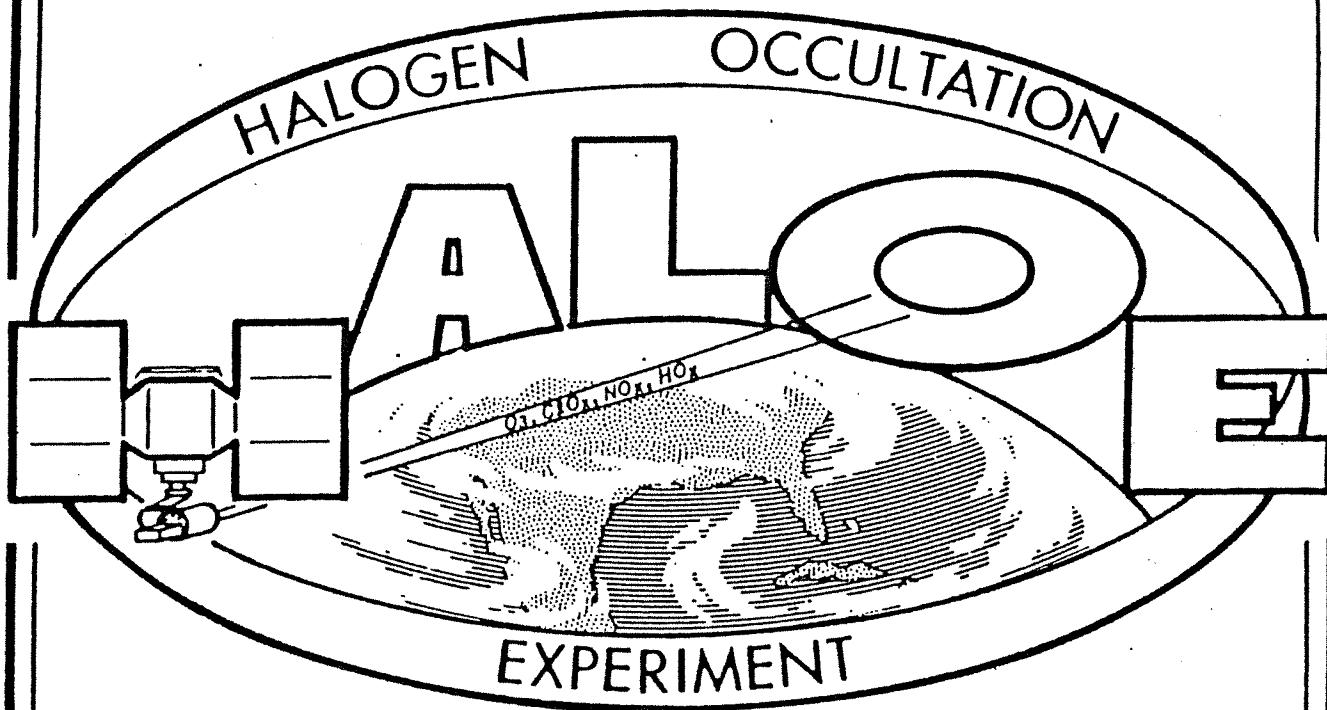
In brief, an optimal estimate of a state vector $\underline{x}$ is made by combining an *a priori* estimate (virtual measurement) $\mathring{\underline{x}}$ with a direct measurement data vector $\underline{y}$, which has a calculated (modeled) functional dependence given by $\underline{y}^{©}(\underline{x})$. The data vector elements are stepped through sequentially, and a given estimate (retrieval) of $\underline{x}$ is used to produce an *a priori* value for the next retrieval. The covariance of $\underline{x}$ is retrieved in a similar manner. The choice of *a priori* eliminates the need for iterations and can model continuity along the tangent track. Data gaps are easily handled, matrix inversions are not required, and the method is not dependent upon the order of data acquisition (*e.g.* scanning sequence).

B.1 Combination of Measurements

Given x_1 and x_2, two independent measurements of a scalar x, with Gaussian statistics and respective variances σ_1^2 and σ_2^2, the maximum likelihood estimates $\hat{x}$ of x and of its variance ($\hat{\sigma}^2$) are (see [17]):

$$\hat{x} = \left(\frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2}\right)^{-1} \left(\frac{x_1}{\sigma_1^2} + \frac{x_2}{\sigma_2^2}\right) \qquad \text{(B.1a)}$$

The Halogen Occultation Experiment (HALOE) Data Validation Plan



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Version 2

July 1, 1991
NASA Langley Research Center

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THE HALOE VALIDATION PLAN

1.0 INTRODUCTION

1.1 Experiment Overview

The Halogen Occultation Experiment on UARS operates using the principle of solar occultation to sound the middle atmosphere. The gas filter correlation spectroscopy method is used in the ≈ 2.5 μm to 5.3 μm spectral range to measure vertical mixing ratio profiles of HCl, HF, CH_4, and NO, and the broadband radiometer technique covering ≈ 6 μm to 10 μm is used to measure profiles of NO_2, H_2O, and O_3. An eighth channel centered in the 2.7 μm CO_2 band is used to retrieve temperature versus pressure profiles needed for the constituent measurements. Table 1-1 lists the gases measured by HALOE, spectral bands, altitude ranges over which mixing ratio profiles will be measured, horizontal and vertical resolution, and temporal resolution. Correlative measurements are needed for validation purposes over as much of the listed altitude ranges as possible.

Table 1-1. HALOE Measurement Objectives

Atmospheric Constituent	Spectral Range*, cm^{-1}	Alt. Range, km Vert. Resol., km	Horizontal Resolution	Temporal Resolution
HCL	2900 to 2980 (3.40 μm)	10 to 60 2	• zonal mean alt. vs. lat. cross section	Biweekly, Monthly, Seasonal
HF	4025 to 4135 (2.45 μm)	10 to 60 2	• altitude vs. longitude at a given latitude	↓
CH_4	2855 to 2920 (3.46 μm)	10 to 70 2		↓
NO	1878 to 1922 (5.26 μm)	10 to 70 2	• global coverage	↓
H_2O	1497 to 1523 (6.60 μm)	10 to 65 2		↓
O_3	960 to 1065 (10.04 μm)	10 to 70 2		↓
NO_2	1585 to 1615 (6.25 μm)	10 to 55 2		↓
CO_2 (Press.)	3530 to 3610 (2.80 μm)	10 to 70 2		↓

*5% Relative Spectral Response Points

Since HALOE relies on solar tracking during sunrise and sunset to make measurements, the geographic coverage is more limited than it is for a limb emission experiment. Approximately 15 occultations occur in each hemisphere each day, giving ≈ 900 events per month. A typical tangent point latitude versus time coverage for 1 year is shown in Fig. 1-1.

1.2 Validation Plan Summary

This validation plan is intended to be a detailed, working document which describes the essential points of the HALOE instrument design and operation, the main features of the instrument laboratory characterization that affect science output, a discussion of error sources, and a listing of error magnitudes for each channel. It also describes the approach to be followed for HALOE data validation and gives an outline of activities to be pursued after launch to carry out the validation process. It is a reference document which will be used throughout the mission.

2.0 DESCRIPTION OF THE HALOE PHYSICAL MODEL

2.1 Instrument Concept and Basic Equations

The HALOE gas filter instrument concept is illustrated schematically in Fig. 2-1. Solar energy N_s passing through the HALOE filter with transmission τ_f is split into two paths; one includes a gas cell containing the gas of interest (e.g. HCl in Fig. 2-1) with transmission τ_g, and the second is a vacuum path with transmission τ_v. After detection by detectors D_1 and D_2, the signals are sent to a differencing amplifier where voltage ΔV is developed. The instrument is balanced to a minimum ΔV value using the electronic gain adjustment G in the gas path when HALOE views the Sun outside the atmosphere (which is the case for Fig. 2-1). When HCl is encountered in the atmosphere during sunrise or sunset, an atmospheric transmission τ_a arises which causes ΔV and V to change. These changes can then be related to the tangent point mixing ratio of HCl. As already noted, there are three other gas filter measurements for HF, CH_4, and NO. Indium Arsenide detectors are used for HCl, HF, and CH_4, while HgCdTe is used for NO. The spectral bands and gases causing interfering signals in these regions are shown in Table 2-1.

Table 2-1. HALOE Gas Filter Channel Spectral Bands and Interfering Gases

Channel	Spectral Region*	Interfering Gases
HCl	2900-2980 cm^{-1}	CH_4, NO_2, H_2O, O_3, Aerosols, C_2H_6?, CH_3Cl?, H_2CO?
HF	4025-4135 cm^{-1}	CH_4, H_2O, Aerosols, N_2O?, Solar CO
CH_4	2855-2920 cm^{-1}	H_2O, HCl, NO_2, Aerosols, C_2H_6?, O_3?
NO	1878-1922 cm^{-1}	H_2O, CO_2, N_2O, CH_4, Aerosols, Solar CO?

*5% Relative Spectral Response Points

The gas filter channel modulation signal formulation is described in Equation 2-1. The modulation signal M is made up of a wide band term containing the broad filter for the HCl channel having a transmission τ_{fw} and a narrow band term containing a narrow band filter function τ_{fN}, which ideally is defined by the gas cell absorption lines. N_s

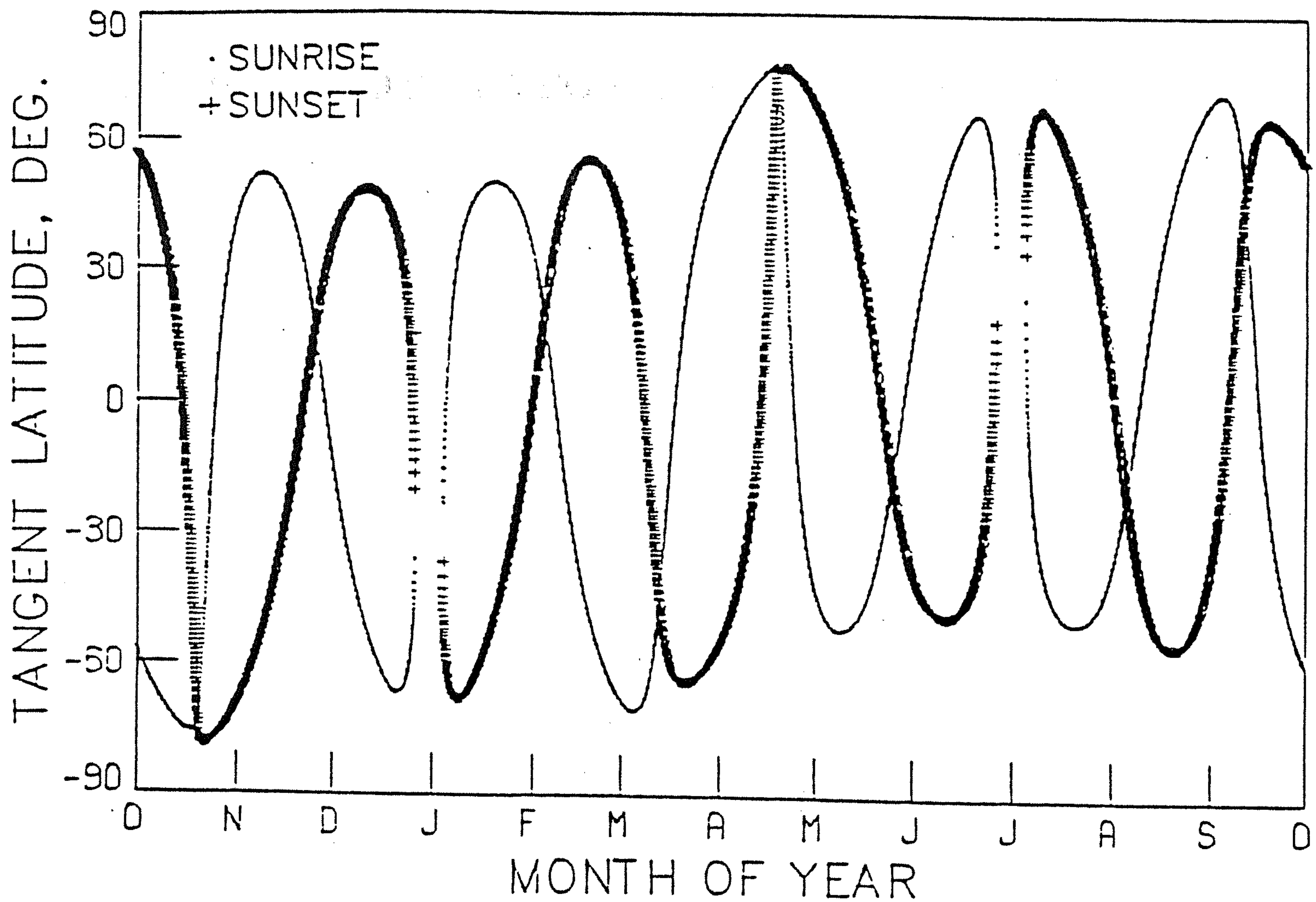


Figure 1-1. HALOE latitude versus time coverage for an October 12, 1990, launch.

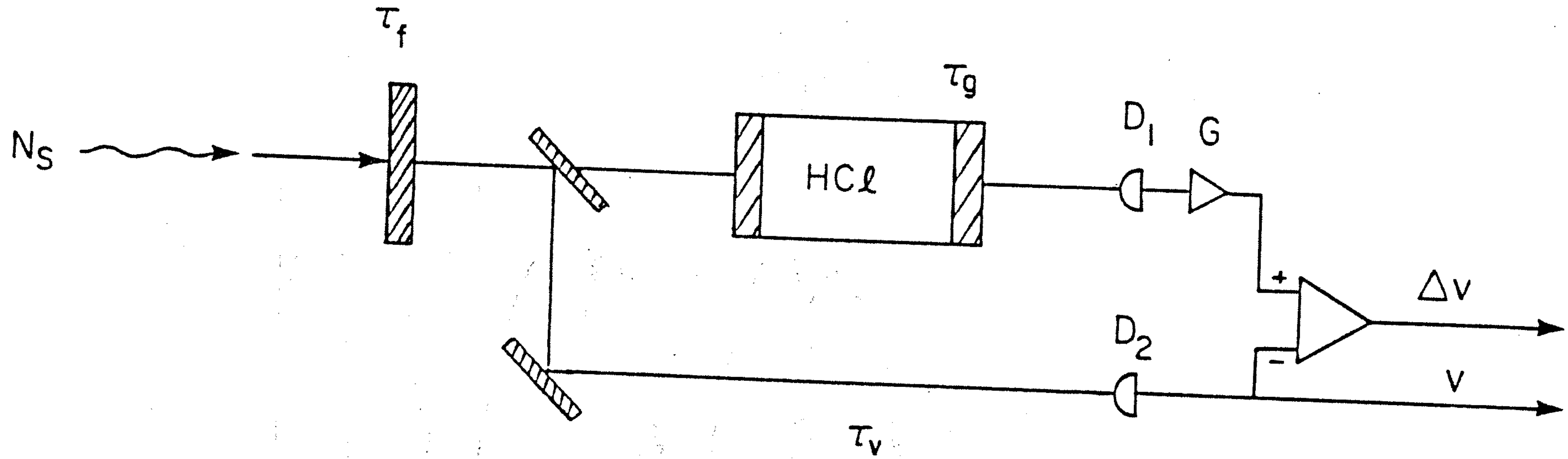


Figure 2-1. The HALOE Gas Filter Instrument Concept

represents the solar irradiance and v is wavenumber. Note that the gain adjust value $\overline{G}$ is equivalent to the reciprocal of the mean gas cell transmission $\overline{\tau_g}$. The modulation signal is equal to the measured ΔV divided by V at every altitude point. The wide band term which contains most of the interfering gas signal effects is measured directly by the vacuum path voltage V. The narrowband term which contains the primary information on the gas being measured (e.g. HCl) is equal to the sum of the measured modulation M and ($\overline{G}$ -1) times the measured wide band signal V all divided by ($\overline{G}$ -1). The narrowband signal also contains a residual interfering gas signal due to absorption line wings. Since the differences ΔV are being measured to 2 parts in 10^5, the HALOE measurement is very sensitive to the gas of interest. It is also sensitive, however, to error effects due, for example, to slight changes in optical alignment caused by thermal changes in the instrument or, as another example, small fixed misalignments in the field-of-views of the two detectors on the horizon. These and other effects have been well characterized as explained in Section 3 of this plan. Adjustments to the modulation signal to correct for thermal changes or changes in detector responsivity during an occultation event are determined using an on-board reference blackbody source signal. The narrowband and wideband filter functions are shown in Figs. 2-2 and 2-3, respectively, for HCl as an example.

$$M = (\overline{G} - 1) \left[\frac{\int_{v_1}^{v_2} N_S(1-\tau_a)\, \tau_{fN}\, dv}{\int_{v_1}^{v_2} N_S\, \tau_{fN}\, dv} - \frac{\int_{v_1}^{v_2} N_S(1-\tau_a)\, \tau_{fW}\, dv}{\int_{v_1}^{v_2} N_S\, \tau_{fW}\, dv} \right] \qquad (2\text{-}1)$$

Where:

$\overline{G}$	=	$1/\overline{\tau_g}$
τ_g	=	mean gas cell transmittance
τ_a	=	atmospheric limb transmittance
τ_{fN}	=	narrow band filter function
τ_{fW}	=	wide band filter function
v	=	wavenumber

The radiometer measurements made by HALOE are much more simple in concept than the gas filter observations. A radiometer measurement can be described by the vacuum path signal shown in Fig. 2-1. Energy from the Sun enters HALOE through an optical filter τ_f and is directed onto a detector. The four dedicated radiometer channels in the HALOE instrument are used to measure O_3, H_2O, NO_2, and temperature versus pressure (CO_2). The detectors are thermistor bolometers operating in a balanced electronic bridge circuit. But as illustrated by Fig. 2-1, the V portion of the gas filter channels also serve as radiometer channels. The radiometer signal formulation can be expressed as:

$$V = C \int_{v_1}^{v_2} N_S\, \tau_a\, \tau_{fW}\, d_v \qquad (2\text{-}2)$$

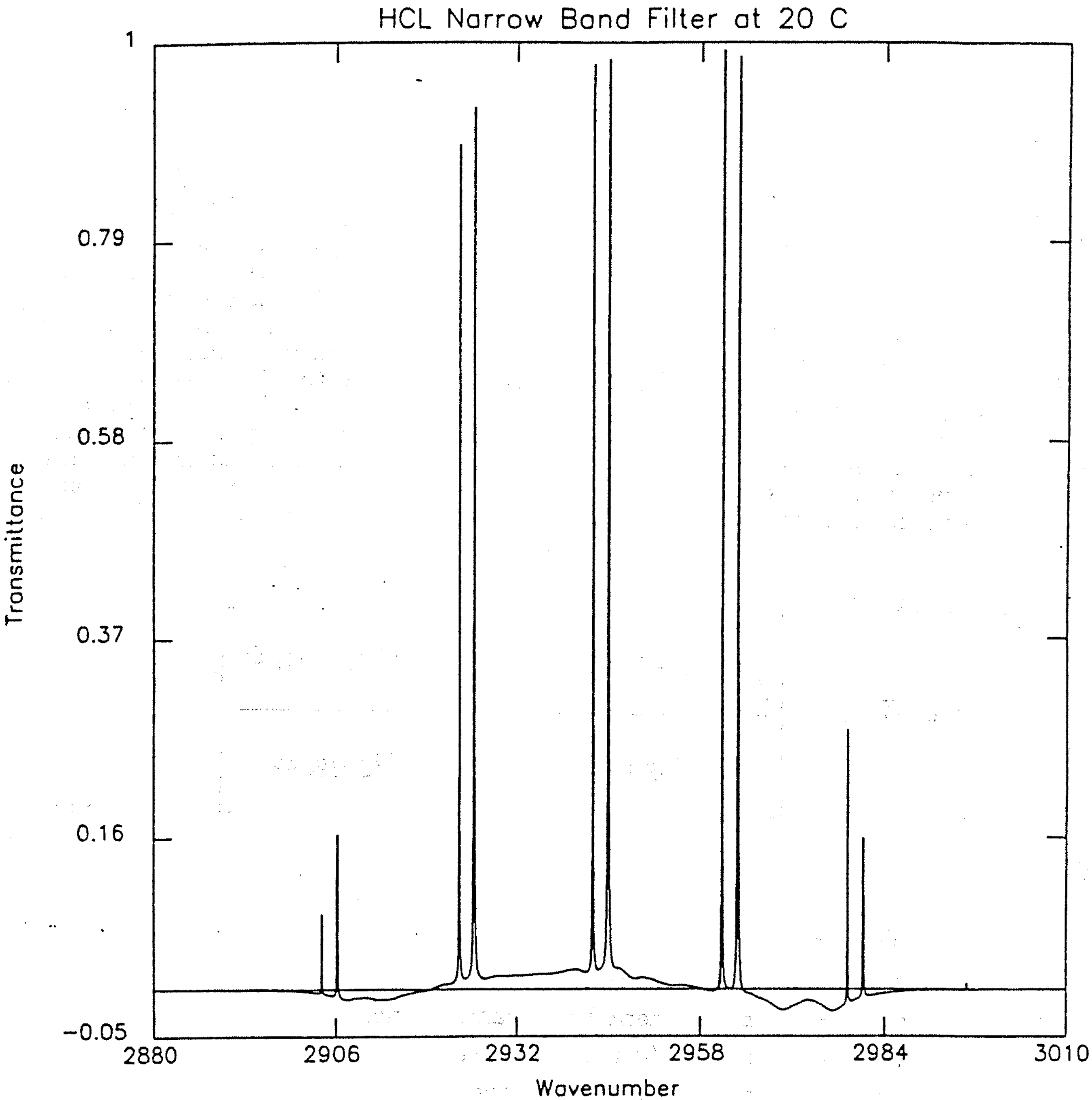


Figure 2-2. HALOE HCl Channel Narrowband Filter Function τf_N

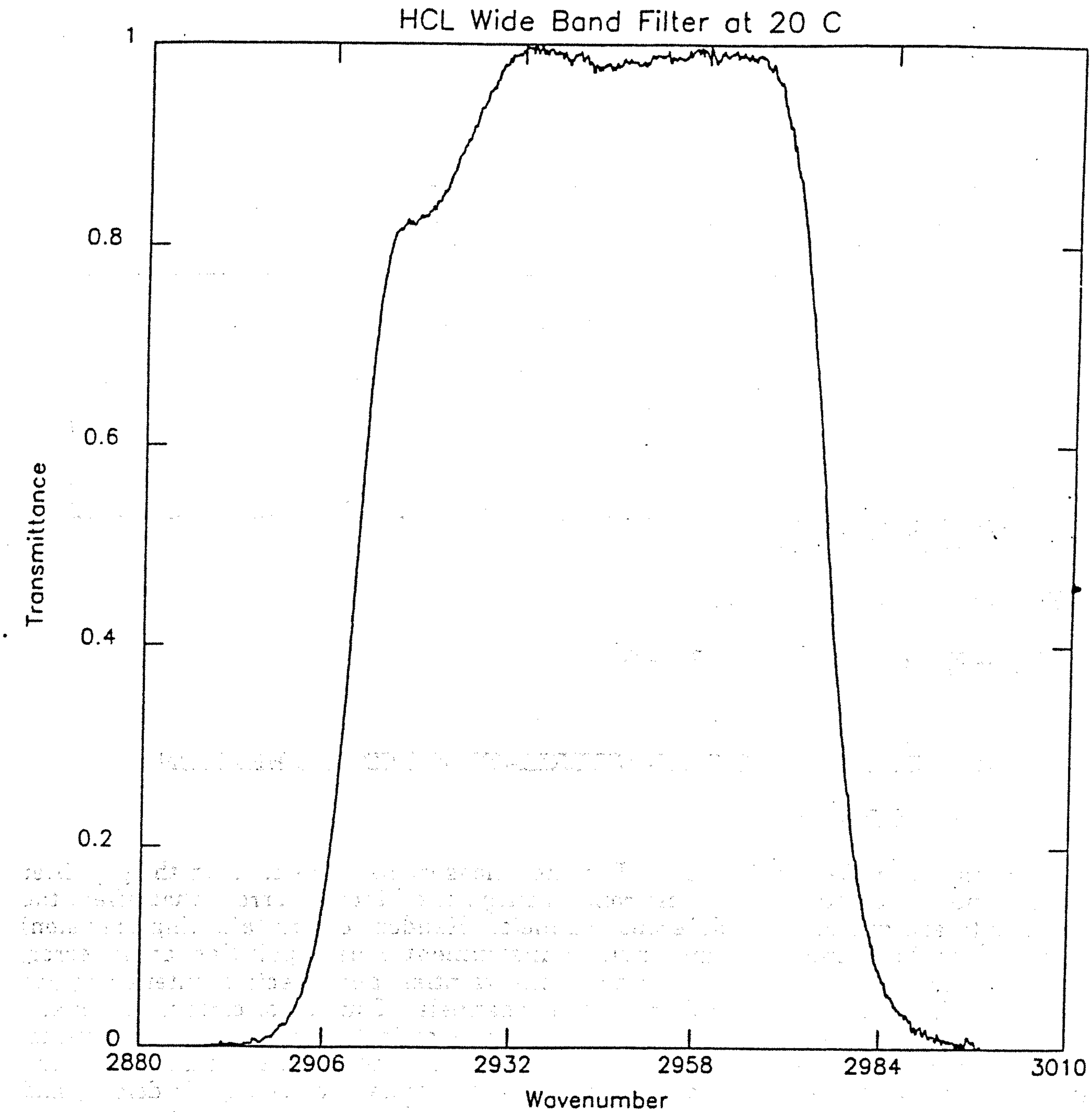


Figure 2-3. HALOE HCl Channel Wideband Filter Function τfW

where V is voltage, C is a constant of conversion from radiance impinging on the detector to volts, N_s is solar irradiance, τ_a is the atmospheric transmission, τ_{fw} is the broadband optical filter, and v is wavenumber. Table 2-2 shows the spectral bands for the radiometer channels and the gases which cause interfering absorption in these bands. The data processing involves division of V at any altitude Z by V_0 the exoatmospheric value, to give $\overline{\tau}_a$, the average atmospheric transmission over the bandpass. Using this approach, a relative measurement is made, thereby eliminating the need for absolute calibration and reducing or essentially eliminating errors due to knowledge of the solar intensity.

Table 2-2. HALOE Radiometer Channel Spectral Bands and Interfering Gases

Channel	Spectral Region*	Interfering Gases
CO_2	3530-3610 cm^{-1}	H_2O, N_2O, Aerosols
NO_2	1585-1615 cm^{-1}	H_2O, CH_4, O_2 (P Induced), N_2O, Aerosols
H_2O	1497-1523 cm^{-1}	CH_4, O_2 (P Induced), Aerosols
O_3	960-1085 cm^{-1}	H_2O, CO_2, CH_4, N_2O, Aerosols

*5% Relative Spectral Response Points

2.2 Forward Model *(to be completed)*

2.3 Inversion Approach *(to be completed)*

3.0 INSTRUMENT CHARACTERIZATION AND CALIBRATION

3.1 Accuracy and Precision

As discussed in Section 2.0, HALOE makes measurements using both the gas filter and broadband radiometry techniques; consequently, the kinds of errors that affect the measurements are different for different channels. Random errors (affecting precision) are common to both methods and include instrument noise, pointing angle error, digitization effects, atmospheric temperature uncertainties, and effects of interfering gas mixing ratios that must be inferred from other channels. Sources of certain systematic errors which are common to both experiment approaches include interfering gas effects, atmosphere temperature and reference pressure errors, optical filter characterization uncertainties, linearity errors, errors associated with removal of electronic delays, and errors occurring when the field-of-view (FOV) function is "deconvolved" from the data.

Some additional systematic errors which affect only the gas filter measurements include knowledge of the spectral properties of the gas cell (expressed as an error in cell mass path pressure and temperature), errors in the slope of the gas path to vacuum path spectral response ratio, uncertainties in modulation signal drift which arise because of the gas filter differencing technique (this places stringent requirements on optical stability), errors due to strict linearity matching of the two gas filter detectors, optical crosstalk, FOV mismatch between gas and vacuum path signals, errors in the ΔV to V gain ratio, errors in the ΔV balance value measured outside the atmosphere, and errors in knowledge of spacecraft velocity used to make corrections for the Doppler effect. Solar physics uncertainties due, for example, to variations in solar CO lines across the solar limb can cause additional errors. The random error components which define precision and the combination of random and systematic instrument errors which determine accuracy are described in the remainder of this section. Characterization of key instrument parameters needed for data reduction and the magnitudes of random and systematic errors, as well as accuracy are also described.

3.2 Spectral Response

The HALOE instrument end-to-end spectral response was determined using a specially designed grating monochromotor, in combination with a 2800K solar simulator source. The relative spectral response was measured in every HALOE channel with a spectral resolution ranging from 2-4 cm^{-1}. In addition, the spectral properties of the optical filters for each channel were measured using a Nicolet 0.06 cm^{-1} resolution interferometer. The filters were measured over a temperature range from 10°C to 30°C in order to ascertain any temperature effects. The filters were found to shift in center wavenumber and spread in width with temperature. They also shifted and changed width as a function of angle of incidence of the beam on the filter. These properties are defined in Table 3-1. The end-to-end spectral responses, including the gas to vacuum path spectral response ratios for the gas filter channels and details of the test data analysis are described in a report by Benner and McInerney (1991).

Table 3-1. Optical Filter Temperature and Tilt Angle Properties

Channel	Temperature Shift and Spread Function*		Tilt Shift and Spread Function**	
	$A(x10^{-2}/°C)$	$B(cm^{-1}/°C)$	C (Unitless)	$D(cm^{-1})$
HCl	-0.069	1.65	0.9937	16.4
HF	0	-0.38	0.994	22.6
CH_4	-0.030	0.493	0.994	13.6
NO	-0.0701	1.0975	1.0005	0
H_2O	0	-0.100	-	-
NO_2	0	-0.0099	-	-
O_3	0	-0.1144	-	-
CO_2	-0.0545	1.62	-	-

*used in the equation $\tau(T, \nu) = \tau_0(T_o, \nu_o + \Delta\nu)$ where $\Delta\nu = A(T-T_o)\nu + B(T-T_o)$
**used in the equation $\tau(\theta,\nu) = \tau_0(0, \Delta\nu)$ where $\Delta\nu = C\nu + D$

Another spectral element for the gas filter channels is the gas filter cell. The spectra of flight cells installed in HALOE were measured extensively with the Nicolet interferometer, and a non-linear least squares spectral line fitting program was developed to allow inference of the optical mass path that gives the best fit to the spectral line structure observed with the interferometer. This was done for both the gas filter cells and gas cells located on the instrument calibration wheel. The results of these studies are provided in Tables 3-2a and 3-2b.

Table 3-2a. Gas Filter Cell Parameters

Gas Filter Cell	Serial Number	Inferred Parameters	
		P(atm)	Mixing Ratio
HCl	L22	0.1	0.12
HF	F12	0.2	0.43
CH_4	H35	0.61	1.0
NO	N45	0.10	0.10

Table 3-2b. Calibration Wheel Cell Parameters

Calibration Wheel Cell	Serial Number	Inferred Parameters	
		P(atm)	Mixing Ratio
HCl	L61	0.07	0.024
HCl	L66	0.01	0.07
HF	H52	0.10	0.104
HF	H56	0.05	0.030
CH_4	H73	0.42	1.0
CH_4	H78	0.10	1.0
NO	N84	0.07	0.02
NO	N88	0.005	0.092

Errors can exist in knowledge of the filter shift and spread functions, the filter relative response background slope, random measurement errors in the relative spectral response at a given wavenumber, and errors in the inferred mass path of the gas filter cell which directly affects measurement scale error.

3.3 Spatial Response

The optical field-of-view (FOV) for each HALOE channel has been extensively measured during the test program. These data were taken by scanning a knife edge or a narrow slit (10 percent of the FOV width) between HALOE and a solar simulator source, and by scanning the FOV across the surface of the actual Sun from the ground. The primary parameters characterized in these tests were the normalized FOV function, mismatch between the gas and vacuum path FOV functions, and the degree of off-axis rejection. The most sensitive parameter of these three is the FOV mismatch which must be known to a high accuracy. Fortunately, this parameter can be measured both in the laboratory and possibly in orbit with sufficient accuracy. Test results obtained from knife edge and solar scans show that the centers of the two FOV's differ by < 0.3 arc seconds. The off-axis rejection properties of the four gas filter channels and ozone measured during the "Sun Look" Test are shown below in Table 3-3. The other channels did not have enough signal-to-noise for a meaningful measurement. By inference, however, since all channels view the atmosphere through the same telescope, the off-axis rejection should be comparable.

Table 3-3. HALOE Off-Axis Rejection Measured During Ground-Based Solar Scans

Position of FOV Center from Solar Edge (arc min)	Channel Response (%)					Requirement (%)
	HCL	HF	CH_4	NO	O_3	
2	<1	<1	<1.5	<3	<3	<5
4	<1	<1	<1	<1.5	<1	<1
6	<0.03	<0.05	<0.054	<0.02*	-	<0.7
10	<0.01	<0.014	<0.018	<0.02*	-	<0.2
60+	<0.003	<0.004	<0.006	<0.02*	-	<0.01

*The limited signal in this channel puts the detection limit at 0.02%.

Further details of the FOV analysis, the actual data, and discussion of error effects are described in a report by Richardson and Gordley (1989). Optical cross talk between channels was carefully measured and shown to be a negligible error effect.

3.4 Pointing

The HALOE pointer tracker hardware is digital with a stepper motor powering a linear harmonic drive system. Pointing and tracking of the Sun is controlled by coarse Sun sensors in azimuth and elevation while acquiring the Sun; but after acquisition, the elevation control shifts to a fine Sun sensor. Coarse sun sensors are still used in azimuth during the track mode. The elevation fine Sun sensor consists of a 256-element reticon diode array which has diodes spaced at ≈ 0.3 arc min (≈ 0.3 km on the Earth limb). The array spans more than twice the entire Sun angular extent, thereby providing a continuous measurement of the extent during an occultation. It is important that the Sun sensor and infrared telescope be properly boresighted and that the IR telescope be centered on the solar disk so that any azimuthal motions during an event cause a minimum noise signal. This boresighting has been measured on the ground with a rate table, solar simulator source system, and by viewing the Sun. An orbital calibration procedure has been developed to check this alignment in orbit and, if needed, to make adjustments to the IR telescope position on the Sun. The most sensitive parameter affecting errors in retrieval gases from HALOE is uncertainty in knowledge of where the telescope FOV is at at any instant of time. This will be known, based on test data, to with ±12 arc seconds in elevation (1σ) and ±15 arc seconds in azimuth.

3.5 Electronics

The presence of electronics introduces several error sources which must be taken into account during HALOE data reduction. These error sources include signal distortion due to amplitude reduction and phase delay, solar signal to reference signal, and reference signal to solar signal crosstalk, detector responsivity variations, and opto-electronic nonlinearity.

Amplitude reduction and phase delay have been accurately measured as a function of frequency by conventional electronic techniques. The resulting Bode plots have been analyzed and show that any resulting amplitude and phase errors are known to the one percent level. Any distortion due to uncorrected error from this source will be small in the total experiment.

Crosstalk results from the fact that no chopper waveform is a perfect square wave. As a result, harmonic signals are always present and, in the case of the HALOE gas filter channels, this causes a component of the signal from the atmosphere chopped at ≈ 150 Hz to be coupled (crosstalked) into the reference blackbody signal at ≈ 300 Hz. Since the reference signal is used to make corrections to the atmospheric signals during an event, the effects of solar-to-reference crosstalk must be removed before using the reference signal ΔR in the data reduction process. The solar-to-reference crosstalk was measured on the ground in two ways: in the laboratory with a knife edge to block the solar simulator and by scanning onto and off of the Sun during a period when HALOE was positioned to see the Sun during special "Sun Look" tests. Solar-to-reference crosstalk was found to be a function of the magnitude of both V and ΔV. The correction to the measured ΔR can be expressed as a linear function of V and ΔV by the equation

$$\Delta R_c = A \bullet V + B \bullet \Delta V.$$

The coefficients are given in Table 3-4. Reference-to-solar crosstalk will also introduce a small, but measurable, error into the atmospheric signal due to the fact that energy from the 1100K reference blackbody is incident on the detector which is also receiving energy from the Sun. This error, too, has been measured in the laboratory and will be corrected during the HALOE data reduction process. Both crosstalk values will be routinely measured in orbit by scanning onto and off of the solar disc. The correction coefficients will be redetermined once HALOE is in orbit, and then they will be routinely updated.

Table 3-4. Solar-to-Reference Crosstalk Correction Coefficients

Channel	Coefficient	
	A	B
HCl	3.92 ± 0.71	-0.246 ± 0.12
HF	3.15 ± 0.81	-0.914 ± 0.18
CH_4	-3.34 ± 0.66	-0.442 ± 0.31
NO	-3.72 ± 1.4	-0.300 ± 0.13

Detector responsivity variations can occur because of detector aging or because of temperature effects which cause optical alignment changes. Representative flight backup detectors are being monitored for changes due to aging, and these data will be used to evaluate detector performance in orbit. The temperature effects are described in Section 3.6.

Opto-electronic linearity is of particular interest for the gas filter channels where the detector response as a function of solar signal on both detectors must be closely matched. The electronics response for each detector must be matched as well. This requirement is stringent since a radiance difference of 2 parts in 10^5 is the specified noise level. The end-to-end linearity of the HCl, HF, and CH4 channels was determined during the "Sun Look" Test by placing wire grid attenuators in front of the HALOE telescope while viewing the

Sun. Attenuators of approximately 15 percent, 20 percent, and 50 percent were used. Insufficient signal existed to determine NO linearity in this test. The grids were rotated in place through angles of 60° and 120° to test for polarization effects and none were found. The requirement is that the deviation in ΔV due to nonlinearity, be a small fraction (< 1 percent) of ΔV itself. The linearity observed is shown in Table 3-5. Note that linearity requirements are met in the three channels which had enough signal. An upper limit can be placed on the linearity effect by changing the intensity of the laboratory solar simulator and observing changes in modulation. In this case, the NO channel showed the best linearity performance of all the modulation channels, lending confidence that it, too, meets requirements.

Table 3-5. Gas Filter Channel Linearity Data Collected During the Sun Look Test

Channel/ Attenuator Value	Change in Signal (NEM)*			Allowable Change in Signal (NEM) for 10% Attenuator
	15%	20%	50%	
HCl	<1	<1	2-3	5
HF	<1	<1	<1	1
CH_4	<5	<5	14-18	50
NO	← **Insufficient Signal** →			15

*1 NEM is the amount of change in modulation required to equal the measured noise level.

The linearity for the radiometer channels was difficult to observe in the Sun Look Test because of atmospheric attenuation. The results for the blackbody intensity change test are shown in Table 3-6.

Table 3-6. Radiometer Channel Linearity Data Collected During the Blackbody Intensity Test.

Channel/ Intensity Change	Change in Signal from a Linear Response (%)				Allowable Change in Signal from a Linear Response Attenuator (%)
	10%	15%	20%	50%	
CO_2					<0.1
NO_2					<0.1
	----------	----------	---<.05---	----------	
H_2O					<0.1
O_3					<0.1

Based on the data in Tables 3-5 and 3-6, even assuming the deviation from linearity can only be corrected to one-half its value, the errors in retrieved mixing ratio will be very small.

3.6 Thermal Sensitivity

The thermal sensitivity of the instrument end-to-end spectral response is driven by changes in the optical filter. As already noted in Section 3.2, this variation has been well characterized and modeled. The gas filter detectors have temperature-dependent responsivities, but these detectors are clamped at a fixed temperature by thermo-electric coolers. The bolometer detectors, on the other hand, float at the mainframe temperature. The change in responsivity is removed to first order by use of the compensating flake data, but there are still residual drifts present.

The gas filter data are also subject to erroneous signal changes due to small thermally induced optical misalignments. Some of the latter changes can be corrected for by using the blackbody reference signal as mentioned briefly in Section 2.1. Testing experience has shown, however, that this does not remove all the thermal drift effect. The approach that has been developed is to use empirically derived models of the drift that use optical mainframe temperature data. A formulation that has worked well in ground thermal vacuum testing is:

$$\Delta M = A_1 \Delta T_1 + A_2 \Delta T_2 + \ldots\ldots\ldots A_N \Delta T_N \quad (3\text{-}1)$$

where ΔM is the thermally induced modulation change and the ΔT's are the changes in temperature from a reference value at various points on the optical mainframe. The A's are regression coefficients which can be derived from a series of modulation and temperature observations. We plan to determine these coefficients in orbit using the temperature data and modulation changes observed before the sensible atmosphere is encountered. Based on data collected thus far, we estimate that on-orbit modulation errors due to thermal drift will be ≤ 1 NEM.

A similar empirical fit approach has been developed for thermal drift in the bolometer channels. Again, the thermal vacuum test data were used to derive regression coefficients that will correct for both responsivity and spectral filter changes. Data taken over a 10°C to 30°C instrument temperature range were evaluated, and it was found that a single set of coefficients will apply. The corrected bolometer voltage, V_C, can be related to the measured voltage, V_M, by

$$V_C = V_M \bullet R_i/R_f \quad (3\text{-}2)$$

where R_i/R_f is the system relative responsivity ratio which is governed by both bolometer responsivity change and the spectral filter change. The relative responsivity ratio can be expressed as:

$$R_i/R_f = \frac{1}{\frac{\alpha}{100} \cdot \Delta T + 1} \quad (3\text{-}3)$$

where α is the responsivity temperature coefficient, or the change in responsivity in percent per degree of temperature change and $\Delta T = T - T_i$ or, the change in temperature from the initial value. The responsivity temperature coefficient is given by

$$\alpha = A_0 + A_1 \bullet T \quad (3\text{-}4)$$

where A_0 and A_1 are determined by regression and given in Table 3-7.

Table 3-7. Ground-Derived Regression Coefficients Used to Calculate Bolometer Channel Responsivity Temperature Coefficients

Channel	A_0(%/°C)	A_1(%/°C^2)
CO_2	-0.64297	-2.31839 E-02
NO_2	-0.43904	-1.05426 E-02
H_2O	-0.26729	-2.81826 E-02
O3	-0.68070	-2.03350 E-02

The coefficients in Table 3-7 appear to work well over the temperature range HALOE will experience in orbit. They will be updated routinely in orbit so that any changes in the instrument environment from ground to orbit or with time in orbit, e.g. from a fast event to a hot grazing event will be taken into account. Analysis of these ground data suggest that any thermal drift in the bolometer signals in orbit should be correctable to a level not to exceed the observed channel noise level.

3.7 System Considerations

One of the key parameters in the reduction of the gas filter data is the gain relation between ΔV and V. Errors in this gain translate directly to an error in modulation. No such errors exist for the bolometer channels which are strictly relative measurements. A procedure has been developed for determining the gain relationship directly from HALOE measurements both on the ground and in orbit. These values for each channel will be routinely monitored and evaluated during orbital operations. The signal error due to this uncertainty is very small. Pre-launch values are given later in Table 7-2.

An additional source of error is data system digitization uncertainties. In some channels, the digital step size is less than the measured system noise, and in others, it is comparable. Statistically, the noise added due to digitization is equal to the step size divided by the square root of 12. The step size, the estimated contribution of digitization noise, and the measured system noise are shown in Table 3-8.

Table 3-8. Estimated Digitization Noise and Measured System Noise

Channel	Digital Step Size	Estimated Digitization Noise	Measured System Noise
HCl	0.28 NEM	0.08 NEM	0.2 NEM
HF	0.28 NEM	0.08 NEM	0.4 NEM
CH_4	1.2 NEM	0.35 NEM	0.6 NEM
NO	0.28 NEM	0.08 NEM	0.3 NEM
CO_2	2.44 mv	0.7 mv	0.9 mv
NO_2	2.44 mv	0.7 mv	1.7 mv
H_2O	2.44 mv	0.7 mv	0.7 mv
O_3	2.44 mv	0.7 mv	0.4 mv

3.8 Summary of Error Sources and Magnitudes

Several reports have been prepared describing the HALOE instrument characterization. Some key references include a detailed description of the end-to-end spectral response test by Benner and McInerney (1991), a description of FOV measurements by Richardson and Gordley (1989), a discussion of HALOE spectral parameter requirements by Drayson et al. (1988), and a detailed discussion and outline of procedures for performing a series of corrections to the orbital data by Sullivan et al. (1991). In addition, there are a number of pertinent engineering test reports. These include *Out-of-Field Rejection at Sun Look Test* by Spiers (1988, HALOE-04-318), *Refurbishment Crosstalk Test (Channel-to-Channel)* by Spiers (1988, HALOE-04-335), and *Sun Sensor to Science Telescope Alignment, Sun Look Alignment, and Sun Sensor to Science Telescope Alignment Check* by Jurczyk (1988, HALOE-03-331). A summary of error sources and magnitudes for each channel is given in Table 3-9.

4.0 ERROR ANALYSIS

(JMR & LLG to provide)

Table 3-9. HALOE Error Sources and Magnitudes*

Error Type	Magnitude							
	HCl	HF	CH_4	NO	CO_2	NO_2	H_2O	O_3
• Random Errors								
- Noise	.2 NEM	0.4 NEM	0.6 NEM	0.3 NEM	0.9 mv	1.7 mv	0.7 mv	0.4 mv
- Digitization								
• Modulation	$0.08/\tau$	$0.08/\tau$	$0.35/\tau$	$0.08/\tau$	0.7 mv	0.7 mv	0.7 mv	0.7 mv
• Transmission (τ)	$2x10^{-4}$ x M/τ	$2x10^{-4}$ x M/τ	$8.5x10^{-4}$ x M/τ	$2x10^{-4}$ x M/τ	—	—	—	—
- CH_4 Mixing Ratio	TBD	TBD	--	TBD	--	TBD	--	--
- NO_2 Mixing Ratio	TBD	--	TBD	--	--	--	--	--
- H_2O Mixing Ratio	TBD	TBD	TBD	TBD	TBD	TBD	--	TBD
- CO_2 Mixing Ratio.	--	--	--	TBD	--	--	--	TBD
- N_2O Mixing Ratio	--	--	--	30%	TBD	--	--	TBD
- O_3 Mixing Ratio	--	--	--	--	--	--	--	--
- Atmos. Temp.	3.5K	3.5K	3.5K	3.5K	--	3.5K	3.5K	3.5K
- Pointing Angle (km)	00.6	0.06	0.06	0.06	0.06	0.06	0.06	0.06
• Systematic Errors								
- Aerosols	--	--	--	--	TBD	TBD	TBD	TBD
- O_2 (Press. Induced)	--	--	--	--	--	<5%	<5%	--
- CH_4 Mixing Ratio	3%	TBD	--	--	--	TBD	TBD	TBD
- NO_2 Mixing Ratio	3%	--	TBD.	--	--	--	--	--
- H_2O Mixing Ratio	3%	TBD	TBD	TBD	TBD	TBD	--	TBD
- CO_2 Mixing Ratio	--	--	--	1%	--	--	--	TBD
- N_2O Mixing Ratio	--	--	--	30%	30%	--	--	30%
- O_3 Mixing Ratio	TBD	--	--	--	--	--	--	--
- Atmos. Ref. Press.	.01 x Log(P)	.01 x Log(P)	.01 x Log(P)	.01 x Log(P)	--	0.01 x Log(P)	0.01 x Log(P)	0.01 x Log(P)

*TBD entries will be determined after completion of retrieval simulations

Table 3-9. HALOE Error Sources and Magnitudes (con't)

Error Type	Magnitude							
	HCl	HF	CH_4	NO	CO_2	NO_2	H_2O	O_3
• Systematic Errors (con't)								
- Halfwidth (T = 296K)								
HCl	1%	--	1%	--	--	--	--	--
HF	--	1%	--	--	--	--	--	--
CH_4	1-10%	2-10%	2-10%	>10%	--	1-10%	1-10%	1-10%
NO	--	--	--	10%	--	--	--	--
CO_2	--	--	--	2-5%	2-5%	--	--	2-5%
NO_2	10%+	--	10+%	--	--	20%	--	--
H_2O	5-8%	5-8%	5-8%	5-8%	5-8%	5-8%	5-8%	5-8%
O_3	5-8%	--	5-10%	--	--	--	--	5-8%
N_2O	--	--	--	5-10%	5-10%	5-10%	--	5-10%
- Line Strength								
HCl	1-2%	--	1-2%	--	--	--	--	--
HF	--	2%	--	--	--	--	--	--
CH_4	1-10%	10%	1-10%	>10%	--	>10%	1-10%	5%
NO	--	--	--	5%	--	--	--	--
CO_2	--	--	--	1-3%	1-3%	--	--	1-3%
NO_2	2-6%	--	2-6%	--	--	3%	--	--
H_2O	10%	10%	10%	unpublished	10%	unpublished	unpublished	unpublished
O_3	3%	--	3%	--	--	--	--	1-3%
N_2O	--	--	--	1-3%	1-3%	1-3%	--	1-3%

Table 3-9. HALOE Error Sources and Magnitudes (con't)

Error Type	Magnitude							
	HCl	HF	CH_4	NO	CO_2	NO_2	H_2O	O_3
• Systematic Errors (con't)								
- Gas Filter Cell Mass Path	2%	2%	2%	2%	--	--	--	--
- Spectral Filter								
• Gas/Vac Slope	0.3%/100 cm^{-1}	0.3%/100 cm^{-1}	0.3%/100 cm^{-1}	0.3%/100 cm^{-1}	--	--	--	--
• Filter Spread* (% of value)	20%	--	20%	20%	2%	--	--	--
• Filter Shift ** (% of value)	10%	10%	10%	10%	3%	100%	10%	10%
• Filter Slope	1%	1%	1%	1%	1%	1%	1%	1%
• Random Spectral Response	0.3%	0.3%	0. 3%	0.3%	1%	1%	1%	1%
- Dopper Shift Correction								
- Electro-Optical								
• Modulation or Signal Drift	0.11 NEM/MIN	0.11 NEM/MIN	0.11 NEM/MIN	0.11 NEM/MIN	--	--	--	--
• Linearity	$0.7 x 10^{-4} x \tau$	$0.7 x 10^{-4} x \tau$	$0.7 x 10^{-4} x \tau$	$0.7 x 10^{-4} x \tau$	TBD	TBD	TBD	TBD
• Solar-to-Reference Crosstalk								
ΔV	10^{-3} x M	$3 x 10^{-3}$ x M	$5 x 10^{-3}$ x M	$0.4 x 10^{-3}$ x M	--	--	--	--
V	$0.6 x 10^{-4} x \tau$	$0.4 x 10^{-4} x \tau$	$0.7 x 10^{-4} x \tau$	$0.6 x 10^{-3} x \tau$	--	--	--	--
• Balance Offset	0.09 NEM	0.09 NEM	0.35 NEM	0.09 NEM	--	--	--	--
• ΔV to V Gain	0.0017 x M	0.0017 x M	0.0017 x M	0.0017 x M	--	--	--	--
- Spatial								
• FOV Mismatch	0.0009 x dτ/dz	0.0018 x dτ/dz	0.0009 x dτ/dz	0.00135 x dτ/dz	--	--	--	--
• Electronics & FOV Transfer Function Deconvolution	< 3 NEM	< 3 NEM	< 3 NEM	< 3 NEM	--	--	--	--

*Error in A Coefficient of Table 3-1
**Error in B Coefficient of Table 3-1

5.0 VALIDATION APPROACH

5.1 Introduction

Validation of the HALOE data will occur at all levels from Level 0 (raw data) to Level 3 (cross section data). Validation will consist of (1) data inspection to remove anomalies and any artifacts caused by the data transmission link, changes in instrument power, or changes in instrument temperatures; (2) comparison with correlative measurements; (3) comparison with other satellite data sets; and (4) comparison with model calculations. It is recognized that in many cases, the validation will include a subjective assessment of the data and the comparisons made.

5.2 Level 0 Data

The raw HALOE data will be validated primarily through inspection using instrument trend plots and tabulations of both science and housekeeping signals. The signals will be examined to identify spikes, data gaps, and any other anomalous changes. Instrument health information, including key instrument temperatures, noise levels, gains, crosstalk levels, field-of-view data, calibration wheel data, difference between bolometer flange and flake temperatures, instrument parameters used for software corrections, and the internal blackbody signal stability will be monitored throughout the mission. In addition, the spacecraft position results provided by the Project will be checked continuously throughout the mission for continuity and accuracy.

5.3 Level 1 Calibrated Signals

The HALOE Level 1 results are data which have been corrected for instrument effects, calibrated, registered in pressure, and condensed to a standard 0.3 km altitude spacing. At this stage, therefore, it will be possible to determine atmospheric limb transmission profiles in each of the radiometer channels and modulation signal profiles in the gas filter channels. The next step in the validation process will be to compare these measured signals (before inversion algorithms have been applied) to forward calculations made using correlative measurement underflight data or, where such data are not available and it is appropriate, climatological profiles. Direct comparison of measurements eliminates error amplifications and artifacts normally brought on by retrieval applications and provides the most fundamental validation comparison step. Problems with these comparisons must be resolved before much effort is spent on resolving differences between HALOE retrievals and correlative data.

5.4 Level 2 Retrieved Geophysical Data

5.3.1 Introduction

The next step in validating HALOE data will be to compare retrieved temperature and mixing ratio versus pressure data to correlative measurements and climatological results, where appropriate. In addition, comparisons will be made to 1-, 2-, and 3-D derived model profiles and pressure versus latitude and longitude cross sections.

5.4.2 Comparisons With UARS Correlative Measurements

Clearly, both the UARS correlative measurements (CM) used for intercomparison studies, as well as the HALOE observations, will have error bars.

Therefore, the CM data are not "truth" and do not provide a standard against which the validity of the HALOE observations can be judged. They will be very useful, however, for intercomparisons and will provide a key input to validation studies. The purposes of any intercomparisons will be considered satisfied when either the estimated error bars of HALOE and any CM data overlap or when reasons for the differences are understood.

5.4.3 *Vertical Profile Shapes*

All of the measurements being made by HALOE have been measured previously either from a balloon platform, during the 3-day ATMOS flight on Spacelab 3, or during previous space missions. Also, model calculations exist. The combined data set, therefore, provides a useful source for comparing expected vertical profile shapes with HALOE observations. Even though biases will, without a doubt, exist because of time differences and other factors, the basic profile shape will be an important validation criterion that can be used to assess validity of HALOE results. Evaluation will be more subjective than, for example, comparisons with coincident measurements.

5.4.4 *Latitudinal and Seasonal Changes*

Some gases observed by HALOE, i.e., O_3, H_2O, CH_4, and NO_2 have been observed globally as well as seasonally by instruments on the Nimbus 7 and SAGE satellites. These data, coupled with 2- and 3-D model calculations, can be used as another validation source to compare latitudinal as well as seasonal changes. Again, the evaluation will be subjective since absolute magnitudes are not necessarily expected to be in agreement with previous measurements.

5.4.5 *Temporal Changes*

Another dimension to the validation study is to examine local time changes in the HALOE data. Sunrise/sunset differences are expected for O_3, NO, and NO_2, but are not expected for HCl, HF, CH_4, H_2O, and retrieved temperature versus pressure. Where the solar occultation viewing geometry permits (e.g. the high latitude Southern Hemisphere in mid-October for Fig. 1-1), the sunrise/sunset differences can be carefully examined for consistency with model results and, where available, past observations. Also during summer when there are very little temporal changes expected due, for example, to wave activity in the atmosphere, retrievals of the same parameter measured at different times will be studied and evaluated as part of the validation process.

5.5 Level 3 Cross Section Data

The HALOE Level 3 data will be unlike other UARS Level 3 products because of the geographical coverage provided by the experiment. The HALOE products will include biweekly and monthly zonal mean pressure versus latitude cross sections for each latitude sweep (defined by the maximum northern to maximum southern latitude excursion in a given time period), daily pressure versus longitude cross sections at selected latitudes for each week, and seasonally averaged pressure versus latitude cross sections. Since all of these products are global in nature, the only data sources that can be used for comparison are UARS or other satellite data, past satellite observations (e.g. SAMS, LIMS, SAGE and SAGE II, SBUV, and SME), climatology, and model calculations. In some cases, for selected latitudes, the cross section data from HALOE can be used as a means to interpolate data to a point closer to a correlative measurement site and, thereby, improve the spatial coincidence. This will have to be done carefully recognizing that interpolation brings in additional errors. The Level 3 data will be the last to be validated.

5.6 Channel Validation Sequence

The greatest effort initially will be placed on the temperature/pressure retrievals obtained using the CO_2 channel since all other results depend on these data. The remaining radiometer channels, O_3, NO_2, and H_2O, are similar in complexity to the CO_2 channel, and these measurements will be emphasized next. Finally, the focus will turn to the gas filter measurements for HCl, HF, CH_4, and NO. These measurements are subject to many more corrections than is the case for the radiometer channels. It is expected, therefore, that the validation will require more work and will take longer to accomplish. This discussion is not meant to imply that work will be delayed on the gas filter channels until the radiometer results are validated. The HALOE Team will, in fact, be organized to address all channels simultaneously; it is just that the Team focus will shift to these channels last since they will likely be harder to validate.

6.0 PRE-LAUNCH ACTIVITIES

6.1 In-Orbit Instrument Calibration Plan

6.1.1 Introduction

There are several potential error mechanisms that can be minimized by using data from orbit for calibration. Additionally, there are instrument characterizations done on the ground that can be monitored for change in orbit. These parameters are expected to remain stable throughout the mission and, in most instances, if instability is detected, corrections will be made. In some cases, however, the ground calibration is anticipated to be much more accurate than in-orbit calibration, and routine corrections are not planned. Parameters that will be determined in orbit include random noise, thermal drift signals, solar-to-reference crosstalk values, ΔV to V gain relations, channel linearity, field-of-view mismatch, and relative pointing position. The detailed procedures for use of orbital data to derive this information are described by Sullivan et al., 1991.

6.1.2 Calibration Data Analysis

The HALOE Level 1 data are routinely broken into separate files for each instrument mode and/or calibration command sequence. These mode files are:

1. Track - endoatmospheric data
2. Balance - DAC gain setting
3. Cal Wheel - Cal wheel sequence
4. Solar Scans - Define limb darkening curves
5. Gain Calibration - Provides ΔV to V gain relations
6. Cross-Talk Calibration
7. Pointing Calibration
8. IFOV Mismatch Calibration

Each type of in-orbit calibration can be done with data from one of these files. All calibration data analysis will be done routinely even though only a subset of the calibration results will be used operationally. The data handling sequence showing where the calibration data are used in the processing is depicted in the flow chart in Fig. 6-1.

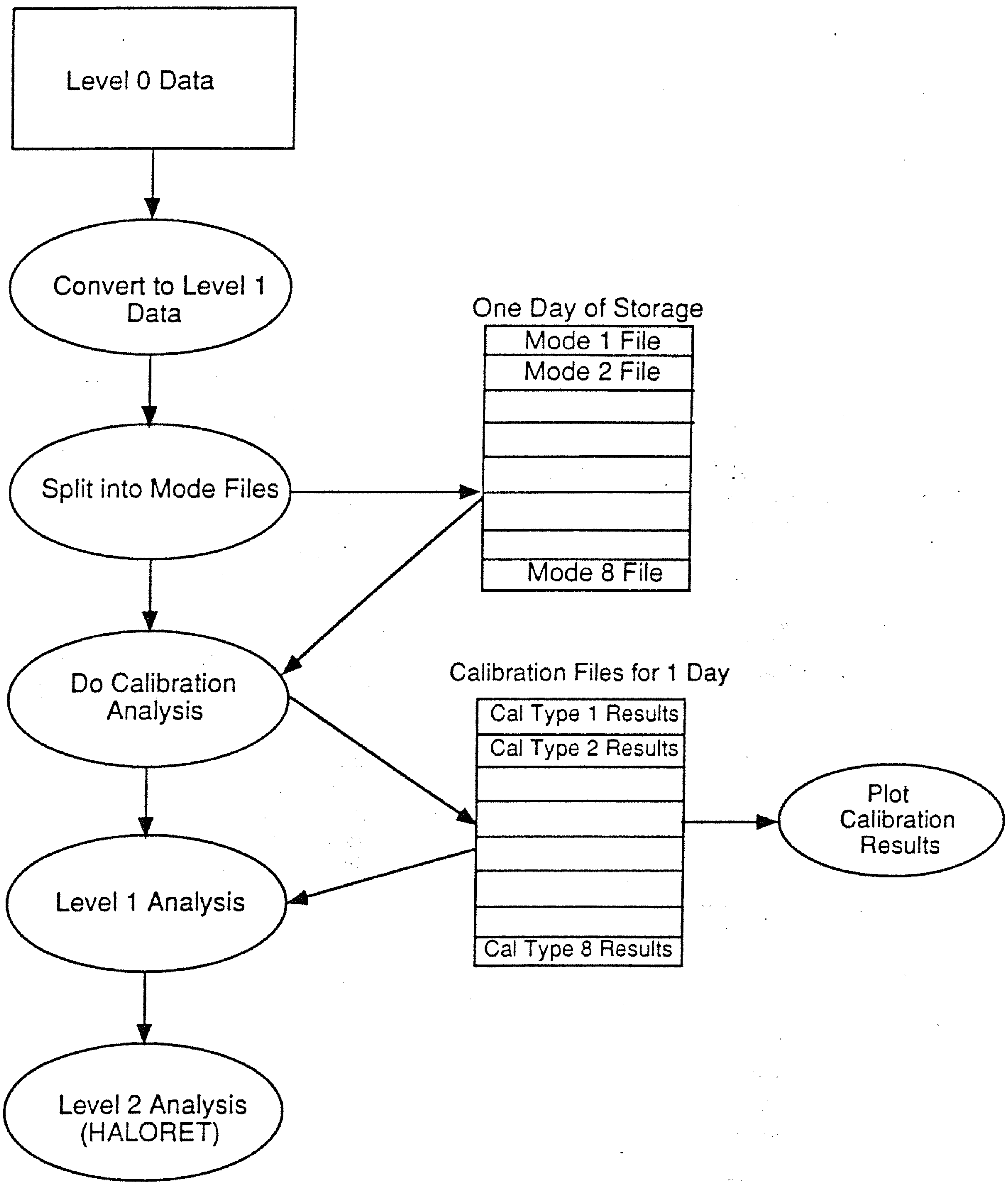


Figure 6-1 Data Handling/Calibration Flow Chart

Operationally, a calibration data analysis routine will use the mode files to derive calibration results and write them to calibration files. Then the Level 1 data processing routines will use this file to insert the calibration results in the data stream headers. The processing algorithms will then retrieve the calibration results from the headers for use in the various processing steps.

6.1.3 Calibration Types

1. Random Noise

   From: Track data

   Used By: Retrieval algorithm

   Stored As: One value for each science parameter. Constant for an event.

   Data Size: 4 words

2. Thermal Drift Signal

   From: Exoatmospheric track data, fitted over several events

   Used By: Level 1 processing in the data correction routine CORINS

   Stored As: Coefficients for fit with time. One set for each event and ΔV channel.

   Data Size: 5 per ΔV channel or 20 words

3. Solar-to-Reference Crosstalk and Zero Offsets

   - Crosstalk

   From: Crosstalk calibration data

   Used By: CORINS where SGC is applied using reference signal

   Stored As: A set of 3 coefficients A, B, C for each ΔV signal in the form of :

   $$\Delta R_T = \Delta R_M + AV + B\Delta V \tag{6-1}$$

   where ΔR_T = true reference signal ΔR; ΔR_M = measured ΔR; V = vacuum path voltage; ΔV = difference voltage

   Data Size: 12 words

   - FOV Offsets

     One constant for each science signal -- 12 in all

4. ΔV to V Gains

   From: Gain calibration data

   Used By: CORINS in ΔV gain conversion

   Stored As: Single constants for each ΔV channel

   Data Size: 4 words

The difference signals must be inferred at the same system gain as V. Therefore, the additional gain on the ΔV signal must be removed by the equation

$$\Delta V_D = \Delta V_M / G$$

where
ΔV_D = true difference signal
ΔV_M = measured difference signal
G = $\Delta V/V$ gain

5. Non Linearity

<u>From</u>: Cal wheel data

<u>Used By</u>: Level 1 data corrections

<u>Stored As</u>: Two coefficients (A&B) for each ΔV channel such that the non-linearity correction is:

$$\Delta V_T = \Delta V_M + A(V_0 - V) + B(V_0 - V)^2 \qquad (5\text{-}2)$$

ΔV_T = True ΔV
ΔV_M = Measured ΔV
V0 = Exoatmospheric V

<u>Data Size</u>: 2 constants per ΔV channel or 8 words

6. Field-of-View Mismatch

<u>From</u>: Lab calibration (and in-orbit data, if necessary)

<u>Used By</u>: CORINS in correcting the track ΔV data

<u>Stored As</u>: An array of values for each ΔV channel. The ΔV correction profiles due to mismatch are obtained by convolving the mismatch function over the appropriate V profile (see Richardson and Gordley, 1989).

<u>Data Size</u>: 61 words for each ΔV channel or 244 words

7. Relative Pointing Positions

<u>From</u>: Pointing calibration mode

<u>Used By</u>: Solar scan processing software package, SSCAN, to create processed limb darkening curves

<u>Stored As</u>: Three constants giving the azimuth of the FOV relative to the diode array azimuth of the diode position of the IFOV on the diode array.

<u>Data Size</u>: 3 words

All calibration data will be placed in the header of Level 1 track data files as well as written to calibration results files. Mission history plots of calibration results will be done over weekly and longer time periods during the mission.

6.2 Intercomparison Data Base

A substantial part of HALOE pre-launch efforts has been devoted to collection of a data base of past measurements and model results that will be used for intercomparison during the post-launch validation period. The core data base will be the UARS climatology developed by Seals (1991). There are some HALOE gases that are not included in this data base because of lack of measurements, and we will fill in these missing gases with balloon measurements (even though these will be single isolated profiles at specific locations) supplemented by model calculations. We will also re-examine the current data base and update it where necessary. Where data are available, we will create a file of monthly zonal mean vertical profiles averaged over 10° of latitude covering as broad an altitude and latitude range as possible and for each month of the year. For diurnally varying gases, i.e., NO, NO_2, and O_3, we will emphasize use of SAGE and SAGE II occultation data for NO_2 and O_3, and model calculations for NO. The ATMOS Spacelab 3 results are also a critical data set for comparison even though data were taken at essentially two latitudes. Our strategy for use of balloon measurements is to collect data from the literature and group results in low ($< \pm 35°$), middle ($35° < Ø < 55°$), and high ($> 55°$) latitude regions. The end result of this activity will be easily accessible files for every primary and interfering HALOE gas grouped according to satellite observations, balloon measurements, or model calculations.

6.3 Data Validation Software

Data validation is a critical phase of experiment implementation which requires flexible, efficient software for data manipulation, data comparison, and display. The primary Level 0 requirement is for trend plot software to identify changes, if any, in important instrument parameters or characteristics. Software needed for Level 1 validation includes programs to plot observed modulation and transmission versus pressure (or altitude) profiles and calculated profiles obtained using the intercomparison data base or climatology. A number of diagnostic tools are needed as well. Points in the data processing stream will be identified where analysis of the interim output will aid understanding of processing software behavior. Procedure files will be developed to stop processing, display parameter plots, e.g. just before solar scan processing or modulation profiles before and after corrections for instrument effects, and then allow processing to resume. Interactive graphic programs will be developed to display data on different scales, in different forms, and over a selectable range of pressures. A statistical intercomparison package will be developed that can select one or many profiles for comparison, including temperature, mixing ratio, modulation and transmission data. The program will provide calculations of mean differences, root-mean square (RMS) differences, standard deviations, and estimates of standard deviations of the mean at all vertical profile points. The statistical package will provide plots of calculated differences and be interactive and highly flexible.

For individual comparisons, the HALOE Level 1 profile will be displayed along with the comparison profile and differences between the two profiles as a function of pressure on the same plot. Similar tasks will be accomplished for the Level 2 validation software. The same statistical package used for Level 1 will also be used for Level 2. Higher processing level plotting software will be developed to display pressure versus latitude zonal mean cross sections of modulation, transmittance, temperature, and mixing ratios retrieved from HALOE and those obtained from other sources, e.g. climatology or other UARS data. Software to display difference cross sections between HALOE and other data will be developed so that geographic regions where particular problems are worst, if any, can be identified. Software will also be developed to calculate and display HALOE sunrise/sunset differences and differences between a given HALOE profile and any other profile at different longitude points. These capabilities will aid in determining measurement precision on orbit and for diagnosing any measurement problems.

6.4 Instrument Test Data and ATMOS Satellite Data Analysis

A significant effort has been devoted to analysis of HALOE laboratory and ground "Sun Look" test data. This activity will continue and be completed before launch to ensure that all anomalies are identified and understood. Several questions remain from the end-to-end Repeat Gas Response Test (RGRT), especially in the HCl and HF channels. These questions deal primarily with comparisons of RGRT data and calculations as a function of instrument temperature for the case of CH_4 gas alone in the simulated atmosphere cell outside the thermal vacuum chamber. A second area of test data analysis is the final end-to-end Spectral Response Test (SRT). These data must be carefully analyzed. Also, the test setup is being characterized, and these results will also be analyzed so that final corrections can be made to the SRT data. A third area of test data being re-examined is linearity of response in both the gas filter and radiometer channels to ensure that proper coefficients, where needed, are incorporated in the flight software.

Another area of pre-launch data investigation currently in progress is analysis of data collected by the ATMOS experiment launched on Spacelab 3 in May of 1985. ATMOS is a high spectral resolution Fourier Transform Interferometer experiment (0.01 cm^{-1} unapodized) which operates in the solar occultation mode. The experiment operated for 2 days providing atmospheric and solar spectra over a broad spectral range that included each HALOE channel and covered the entire mesosphere and stratosphere. Measurements were made at 47°S and 30°N. This data set, therefore, is an invaluable source of atmospheric spectra which is being used to evaluate our knowledge of absorption lines and line strengths of gases absorbing in the various HALOE bands. This analysis will be completed before launch.

6.5 Pre-Launch Data Intercomparison Tests

Upon completion of the intercomparison data base and data validation software, the entire validation system will be tested in order to work out problems, test procedure files, and analyze displays developed. The balloon and climatology data will be used to create a simulated correlative measurements file, and all intercomparison modes will be tested, including accessing the CDHF to select data from other experiments (i.e., MLS, ISAMS, and CLAES) for comparison. The HALOE SIDS data base in the CDHF will be used as the primary HALOE data base in the test. The goal of this test is to exercise and evaluate all validation software.

7.0 POST-LAUNCH ACTIVITIES

7.1 Instrument Engineering Validation

The HALOE instrument will be activated as soon as possible after UARS has reached the planned orbit altitude of 600 km. A contamination witness sample retrieved from Shuttle after it returns will provide critical information needed to decide when activation will occur. The instrument will be powered on, the azimuth and elevation gimbal pyrotechnic devices will be fired, and the instrument will be slewed to the stow position. This will provide an initial gimbal operation check. At the same time, all instrument voltages, currents, temperatures, and mainframe temperature gradients will be checked, compared to predictions, and analyzed to ascertain instrument health. Some science-related engineering parameters can be directly compared to ground values. Table 7-1 shows balance, ΔR, and solar-to-reference crosstalk criteria for use in evaluating on-orbit performance. The balance criteria require that the system be balanced to within one DAC bit in order to accurately monitor ΔR and FOV mismatch.

Table 7-1 Expected Orbital Values of Important Parameters

Channel	Balance ($\delta\Delta V$ differences)*	ΔR**	Solar-to-Reference Crosstalk (δR differences)***
HCl	±0.032	1.0 ± 0.5	< 0.01
HF	±0.020	0.4 ± 0.5	<0.01
CH_4	±0.008	0.8 ± 0.5	<0.01
NO	±0.048	1.4 ± 0.5	<0.01

*The difference between exoatmospheric ΔV at full Sun and exoatmospheric ΔV at no Sun after the system is balanced

**Reference signal ΔR

***The difference in R signals for full Sun and no Sun

Other solar-to-reference crosstalk differences will also be measured and tracked, including the differences $\delta\Delta R$ and $d\Delta R'$ between full Sun and no Sun signals for ΔR and $\Delta R'$. These three quantities δR, $\delta\Delta R$, and $\delta\Delta R'$ all provide information needed to understand the reference signal change due to solar signal crosstalk input.

After a sufficient outgassing time period has passed, a series of on-orbit tests will be carried out during the transition phase from initial activation to routine orbital operations. These tests, conducted over a period of about 4 days, will include a signal drift test, gain/crosstalk determination test, Sun sensor to IR telescope boresight test, and a gas to vacuum channel field-of-view (FOV) mismatch test. More detail on the sequences to be used and a description of other instrument operational modes is included in the HALOE Modes Document (Sullivan 1991, included as Appendix A). During this transition phase, all primary commands to be used later for routine operations will be exercised.

7.2 Initial Instrument Performance Evaluation

7.2.1 Radiometric Performance

The primary radiometric parameters that will be evaluated and tracked during the life of HALOE are system noise in each channel, instrument drift characteristics, maximum/minimum signal levels, overall system gains, and crosstalk values in the gas filter channels. Channel noise values, instrument thermal drift signals, and maximum/minimum signals for science channels will be determined using the drift test. In this test, the Sun is tracked through an entire occultation event from the point of acquisition without taking time for measurements such as solar scans and calibration wheel sequences which would interrupt the data sequence. These data will be analyzed and the noise, drift rate, and signal level results will be compared to ground values and predictions in order to validate understanding of instrument behavior. The gain calibration sequence whereby gains are determined by changing settings on the digital-to-analog convertor (DAC) will provide data on electronic gains and crosstalk values for all channels. These will be compared to ground-determined values. These gains are given in Table 7-2.

Table 7-2 Pre-Launch Gain Values

Channel	Gains		
	ΔR	ΔR'	ΔV
HCl	11.39	85.93	123.37
HF	10.11	75.68	123.59
CH_4	10.92	81.90	26.31
NO	11.23	84.74	123.30

Two drift tests will be conducted, one on the second and the other on the fourth day after activation. The gain/crosstalk calibration will be performed the second, third, and fourth days. Since the data reduction requires accurate knowledge of the gains, initially, gain values will be determined for almost every event. This approach will be evaluated as the mission progresses and trends are studied. The maximum drift rates expected in orbit occur for a grazing event. These predictions are given in Table 7-3 for both gas filter and radiometer channels.

Table 7-3 Expected Signal Drift Rates for the Hot Grazing Event Case Assuming No Empirical Corrections

Channel	Predicted Drift* Over Indicated Time Interval					
	NO SGC Adjustment			With SGC Adjustment		
	15 min	7.5 min	1.5 min	15 min	7.5 min	1.5 min
HCl	7.1 NEM	3.5 NEM	0.7 NEM	5.3 NEM	2.7 NEM	0.5 NEM
HF	5.2	2.6	0.5	1.0	0.5	0.1
CH_4	6.7	3.3	0.7	4.2	2.1	0.4
NO	5.6	2.8	0.6	2.0	1.0	0.2
CO_2	-0.37%	-0.19%	-0.04%	--	--	--
NO_2	-0.20	-0.10	-0.02	--	--	--
H_2O	-0.31	-0.16	-0.03	--	--	--
O_3	-0.35	-0.17	-0.04	--	--	--

*Using empirical corrections developed from changes in exoatmospheric data taken before or after an event, it is estimated that the gas filter and radiometer channel signals can be corrected to within the noise levels.

7.2.2 Calibration Wheel Data

The HALOE instrument includes a calibration wheel just after the first focus formed by the secondary mirror lens in a beam of collimated light. The wheel contains three neutral density filters, eight gas cells (two for each channel), and an open port. This wheel is intended to be a way of measuring instrument stability to the extent possible. This works very well for the neutral density filters but only moderately well for the gas filter ΔV signals. This is because the wheel is introduced in a portion of the optics in a near-field position making the resulting signals highly sensitive to small angular deviations and, therefore, not very useful as an absolute indicator of modulation signals. Nevertheless, the gas filter signals can be used to show relative changes with time and, thereby, aid in detection and diagnosis of any problems with the gas filter measurements.

The signals in all channels for the three neutral density filters (≈ 20%, 60%, and 80% transmission) appear to be very repeatable (to ≈ 1% 1 σ), and they are not a strong function of instrument temperature. These signals, therefore, will be very useful for initial instrument evaluation once it becomes operational. Also, to first order at least, the modulation signals for various calibration wheel positions that were determined in the RGRT for different instrument temperatures can be used as a crude gage of initial gas filter channel performance. Tables 7-4a and 7-4b give the neutral density filter transmissions in each channel, the gas filter signals at three instrument temperatures, the estimated range that the signals will fall within, and the coefficients used to fit the data so that orbital values collected at any instrument temperature can be compared to ground results.

Table 7-4a. Calibration Wheel Modulation Signals Determined on the Ground That Can be Used for Orbital Performance Evaluation

Channel	Cal Wheel Port No.	Modulation Signals			Fit Coefficients*		
		10°C	20°C	30°C	A(NEM)	B(NEM/°C)	C(NEM/°C²)
HCl	5	44 ± 10	39 ± 10	29 ±10	44	0.25	-0.025
	11	100 ± 10	83 ± 10	72 ±10	123	-2.6	0.03
HF	2	306 ± 10	280 ± 10	272 ±10	350	-5.3	0.09
	8	92 ± 10	94 ± 10	82 ±10	76	2.3	-0.07
CH_4	1	1335 ± 50	1313 ± 50	1248 ±50	1314	4.25	-0.215
	7	4528 ± 50	4446 ± 50	4209 ±50	4455	15.05	-0.775
NO	4	36 ± 10	34 ± 10	29 ±10	35	0.25	-0.015
	10	157 ± 10	143 ± 10	130 ±10	172	-1.55	0.005

*Used in the equation $M(T) = A + BT + CT^2$

Table 7-4b. Calibration Wheel Radiometer Signals Determined in Ground Testing Can be Used for Orbital Performance Evaluation

Channel	V Channel Transmission Values		
	Port #9 $\tau_{ND} = 0.2$	Port #6 $\tau_{ND} = 0.6$	Port #3 $\tau_{ND} = 0.8$
HCl	21.2%	61.1%	79.8%
HF	21.8%	59.5%	80.2%
CH_4	20.9%	61.6%	80.0%
NO	19.8%	63.6%	81.7%
CO_2	21.9%	60.6%	80.5%
NO_2	24.5%	66%	82.7%
H_2O	17.8%	63.7%	81.8%
O_3	15.9%	63.0%	81.4%

7.2.3 Pointing System

The HALOE pointing system uses a digital "hunting" method that tracks a given diode location in the reticon array. As the pointer/tracker steps to hold position, it creates a time-varying noise signal which becomes worse as the IR telescope boresight moves further from the Sun centerline. Important measures of the Sun sensor performance include the amplitude of the exoatmospheric V signal changes, and the angles between the IR telescope, the Sun sensor optical axis, and the Sun center itself. The V signal pointer/tracker noise will be obtained from the drift test data described in 7.2.1. The telescope to Sun sensor alignment will be measured in orbit using data from the Boresight Alignment Test. Initially, this test will be carried out on the third and fourth day after activation. The boresight values will be compared to ground-determined results to validate performance.

7.2.4 Field-of-View (FOV)

Two FOV parameters will be routinely used to monitor HALOE stability in orbit. The first is the FOV mismatch function, which is critical to data reduction. This function describes slight misalignments between the gas and vacuum path FOV's. This misalignment has the effect of creating a difference signal ΔV which is unrelated to spectral correlation and, hence, is an error signal source that must be normalized out. These functions have been measured on the ground by scanning a "knife edge" in front of a solar simulator source illuminating HALOE. In orbit, the mismatch will be determined during the FOV test which is planned for days 3 and 4 after activation. This test will be conducted at low β angles when the solar motion, relative to the instrument, is rapid and almost entirely in the elevation direction. Under these conditions, the solar limb approximates and becomes a natural "knife edge." The mismatch will be calculated by analyzing instrument signals as the FOV drifts across the solar edge. A measure of the mismatch for validation purposes is given by the difference between the maximum ΔV and the minimum ΔV as the FOV scans the Sun edge. The values expected in orbit and the inferred differences between the centers of the gas and vacuum path FOV's are shown in Table 7-5.

The second FOV parameter used to evaluate orbital performance is off-axis rejection. This is a measure of scatter off mirror surfaces, for example, due to contamination, dust buildup, or optical alignment changes. A measure of this will be obtained every sunrise and sunset since, during solar scans, the center of the FOV is scanned two FOV spacings past the solar limb. The FOV values measured on the ground are given in Table 7-5.

Table 7-5. FOV Parameters Used for Orbital Performance Evaluation

Channel	Parameter		
	Expected $\delta\Delta V$* (volts)	$\delta\theta$** (arc seconds)	r*** (%)
HCl	±0.30	-0.231	<1
HF	±0.40	0.304	<1
CH_4	±0.08	-0.141	<1.5
NO	±0.30	-0.148	<3
CO_2	--	--	<1
H_2O, NO_2, O_3	--	--	<3

*Difference between the maximum and minimum ΔV as the FOV scans the solar edge.

**Angular mismatch between the centers of the gas and vacuum path FOV's (VAC — GAS).

***The ratio of full-Sun signal to no-Sun signal at a FOV center position 2 arc min from the solar edge measured during the ground Sun Look Test, except for CO_2, H_2O, and NO_2, which are estimates.

7.3 Long-Term Instrument Performance Evaluation

All of the special orbit tests and data studies done immediately after activation will be performed routinely throughout the life of HALOE. Where appropriate, trend plots will be developed in order to quickly analyze instrument behavior. Because the experiment is done in occultation, it is in many ways self-calibrating and not as susceptible to long-term changes as an emission experiment would be. Quantities that will be trended and continually evaluated are summarized in Table 7-6. The calibration wheel data will be especially useful for long-term trend studies. In orbit, HALOE should be in one of the most thermally stable environments of its lifetime. Because of this, the modulations and radiometer signals that are induced by the components on the calibration wheel are expected to remain steady or have little variation. The effects of the near field optics prohibit the use of the neutral density filters as a linearity check on the GFCR channels; however, the transmission detected at each radiometer while viewing a filter should not change during the mission. This will be a very useful health and safety check of the instrument. The gas cells on the calibration wheel can be used to monitor the health and safety of the GFCR channels and can be particularly useful for detecting leaks in the instrument gas cells or for finding problems with the gas path detector.

Initially in orbit, the signals induced by the calibration wheel will be compared to the results collected from thermal vacuum testing. Subsequent calibration wheel data will be trended and correlated with one or more thermistors on the instrument and/or other parameters such as elapsed time since Sun acquisition. The results of these correlations will help develop predictor models for the instrument science signals induced by calibration wheel components.

Table 7-6. Quantities to be Plotted for Trend Analysis

Quantity	Description
Temperature	motors, main frame, detectors
Voltages	motors, detectors
Currents	motors, detectors
Bolometer temperature difference	flange minus flake temperatures
Balance ($\delta\Delta V$)	full Sun - no Sun ΔV
Reference (ΔR)	reference signal difference voltage
Reference (δR)	full Sun - no Sun R
Reference ($\delta\Delta R$)	full Sun - no Sun ΔR
Reference ($\delta\Delta R'$)	full Sun - no Sun $\Delta R'$
Crosstalk (A, B)	% change in A, B coefficients
System noise	1σ variation about exoatmospheric mean
Drift rate	exoatmospheric drift rate in all science channels
Maximum signal	maximum V signals
System gains	ΔR, $\Delta R'$, and ΔV gains
Pointer/tracker noise	amplitude of pointer/tracker induced V signal noise
Boresight angles	telescope to Sun sensor and telescope to Sun center
FOV mismatch ($\delta\Delta V$)	Difference between maximum ΔV and minimum ΔV as FOV scans solar edge
FOV mismatch angle ($\delta\theta$)	Differences between centers of gas/vac FOV's in arc seconds
Off-axis rejection	Ratio of V at two IFOV's past solar limb to V at Sun center
Cal Wheel Neutral Density Transmittance	Standard deviation (%) of τ_{ND} values
Cal Wheel Exoatmospheric Modulation	Change in cal wheel modulation (%)
Blackbody stability	Stability of blackbody voltage, current, resistance
Bit noise remnants	Monitor telemetry for bit noise remnants (H2OBI)

Table 7-6. Quantities to be Plotted for Trend Analysis (con't)

Quantity	Description
Pointer tracker check	Trend azimuth offset pointer tracker check
Fine Sun sensor extend	Monitor FSSBOT - FSSTOP during autobalance and cal wheel
Sun sensor contamination	Monitor parameters VPEAK and CSSMAG during autobalance and cal wheel for contamination effects
Stow position check	Verify sunrise initial azimuth and stow position are in different quadrants
Azimuth track error	Monitor CSSAZ during autobalance and cal wheel to verify CSSAZ <= 0.150.
Elevation track error	Monitor FSSTOP during autobalance and cal wheel to verify 123 <= FSSTOP <= 128
Solar acquisition check	Verify the sunset/sunrise acquisition angles agree with planning aids
Fine Sun sensor diode check	Verify TCOR = 12 and BC OR = 0 during autobalance and cal wheel
V/R ratio	Monitor V/R ratio at center of disk during solar scans
IFOV extent	Monitor IFOV extent during FOV calibration
Modulation uncertainty	Monitor long-term modulation changes by comparing modulation with heavy and light gas concentrations
Gimbal slew rate	Monitor gimbal slew rates during slew to initial position and slew to stow

7.4 Trend Plot Requirements

Temperatures

Temperature trending should be performed on all HALOE temperature parameters with separate trend files created for all periods, stow periods, sunset events, and sunrise events. The separate trend files will be used to monitor overall thermal stow position temperature stability, sunset event, and sunrise event stability.

Temperature parameters to be trended are listed below. Parameters marked with an asterisk should be monitored when survival power is applied.

MFMT	ELEVT	GEATH	GCRT	HFGDT	HFGDT	HFVDT
CH4GDT	CH4VDT	NOGDT	NOVDT	RD03T	SSAT	RDCO2T
HFGCT	HCLFLT	CH4FLT	HFFLT	NOFLT	CALWFT	TBLT1
TBLT3	TBLT4	TBLTS	TBLT6	*TBAT	*CHOPT	*PMIRRT
*AZIMT	*PEAT	*GEAT	*MFAVT			

HCLGDT	HCLVDT
RDNO2T	RDH2OT
TBLT1	TBLT2
*SMIRRT	*AFTOT

Requirements for each trend file are listed below:

Continuous:	Y-axis:	High, low, and mean orbital temperature (stock market style)
	X-axis:	Orbit number
Stow:	Y-axis:	High, low, and mean stow position temperature (stock market style)
	X-axis:	Orbit number
Sunset:	Y-axis:	High, low, and mean sunset event temperature (stock market style)
	X-axis:	Orbit number
Sunrise:	Y-axis:	High, low, and mean sunrise event temperature (stock market style)
	X-axis:	Orbit number

Voltages

Voltage trending should be performed on all HALOE voltage telemetry when the instrument is ON to ensure that system voltages are stable during all modes of operation.

Voltage parameters to be trended and their y-axis limits are listed below:

Parameter	Low	High	Parameter	Low	High
P3.5VM	5.250	5.750	H28VM	28.500	29.500
P3.5VA	5.250	5.750	H28VA	28.500	29.500
PSVM	4.950	5.150	P28VM	29.000	30.000
PSVA	4.950	5.150	P28VA	29.000	30.000
P7VM	7.800	8.300	N28VM	-29.500	-28.500
P7VA	7.800	8.300	N28VA	-29.500	-28.500
P8VM	7.250	7.750	P29VM	28.850	29.100
P8VA	7.250	7.750	P29VA	28.850	29. 100
P1OVM	9.900	10.200	N29VM	-29. 100	-28.850
P1OVA	9.900	10.200	N29VA	-29.100	-28.850
P15VM	14.750	15.000	N1OVR	-10.015	-9.990
P15VA	14.750	15.000	GNDREF	-0.030	0.020
N15VM	-15.050	-14.800			
N15VA	-15.050	-14.800			

Trend plot capability shall be developed to show the voltage telemetry as a function of orbit number, day number, and beta procession on the x-axis and the mean, minimum value, and maximum value on the y-axis.

Housekeeping Currents

Trending should be performed on all housekeeping currents derived from the quiet bus and heater/motor bus power supplies. Currents derived from the quiet bus supply (INSTRI, INSPWR, INSTIM, INSTRIA, and CHOPI) should be trended on a continuous basis. Currents derived from the heater/motor bus should be trended modally during sunset/sunrise events and during stow, since the heater/motor bus current will vary with gimbal activity.

Housekeeping current parameters and y-axis limits are listed below:

Parameter	Low	High	Parameter	Low	High
INSTRI	1.5	2.5	HMIM	0.0	2.0
INSPWR	50.0	75.0	HMIA	0.0	2.0
INSTIM	1.5	2.5			
INSTRIA	1.5	2.5			
CHOPI	0.03	0.04			

Trend plot capability shall be developed to show the quiet bus derived current telemetry as a function of orbit number, day number, and beta precession on the x-axis and the mean, minimum value, and maximum value on the y-axis. Heater/motor bus derived currents shall be plotted as the quiet bus parameters except that two sets of plots showing the sunset/sunrise event performance and the stow performance shall be created.

Bolometer Temperature

Comparisons of the bolometer flange temperatures (RDH2OT, RDNO2T, RDCO2T, RDO3T) to bolometer current (H2OBI, NO2BI, CO2BI, O3BI) derived temperatures obtained using a regression analysis should be trended throughout the mission.

Balance

Balance stability should be trended during solar scans to compare the full Sun balance voltage to the no Sun offset voltage. Trend files should be created that show balance stability during sunset events (Mode 6, Xtask 3), sunrise events (Mode 6, Xtask 15), and the difference between events. Full Sun data should be obtained when FSSTOP = 126 ± 2 and no Sun data should be obtained when FSSTOP = 163 ± 2. The HALOE Flight Operations team will attempt to maintain the difference between full Sun and no Sun below 300mV during routine operations.

	Sunset Data (Mode 6, Xtask 3)			Sunrise Data (Mode 6, Xtask 15)		
Channel	Full Sun	No Sun	Difference	Full Sun	No Sun	Difference
HFDV HCLDV CH4DV NODV	TBD	TBD	TBD	TBD	TBD	TBD

The difference between events will be calculated by subtracting the sunrise difference from the sunset difference.

Separate trend plots should be developed to show the sunset event difference, the sunrise event difference, and the difference between events on the y-axis and the orbit number, day number, or the beta precession on the x-axis.

R Channel Stability

The absolute levels of all R and DR channels will be monitored as a continuous time series to monitor long-term detector stability. R channel data will be obtained 10 seconds from the end of an autobalance sequence.

R Channel Crosstalk

R channel (HFR, HCLR, CH4R, NOR) crosstalk should be monitored during solar scans to ensure that crosstalk characteristics are constant. This should be accomplished by measuring the R signal at the center of the solar disk (FSSTOP = 82 ± 4) and two IFOV's off the solar disk (FSSTOP = 163 ± 4). Trend plots will be created to show the R channel crosstalk on the y-axis and the orbit number, the day number, and the beta precession on the x-axis.

Delta R Crosstalk

Delta R channel (HFDR, HCLDR, CH4DR, NODR) crosstalk should be monitored during solar scans to ensure that crosstalk characteristics are constant. This should be accomplished by measuring the DR signal at the center of the solar disk (FSSTOP = 82 ± 4) and two IFOV's off the solar disk (FSSTOP = 163 ± 4). Trend plots will be created to show the Delta R channel crosstalk on the y-axis and the orbit number, the day number, and the beta precession on the x-axis.

Delta R Prime Crosstalk

Delta R prime channel (HFDRP, HCLDRP, CH4DRP, NODRP) crosstalk should be monitored during solar scans to ensure that crosstalk characteristics are constant. This should be accomplished by measuring the DRP signal at the center of the solar disk (FSSTOP = 82 ± 4) and two IFOV's off the solar disk (FSSTOP = 163 ± 4). Trend plots will be created to show the Delta R prime channel crosstalk on the y-axis and the orbit number, the day number, and the beta precession on the x-axis.

Crosstalk Model Coefficients

Crosstalk model coefficients should be modeled to verify that ground and flight crosstalk characteristics are unchanged. Data from solar scans and the gain calibration can be used for this verification. The percent change in A/B coefficients should be trended.

System Noise

Exo-atmospheric system noise should be analyzed from data obtained during each sunset event autobalance sequence. Channels that should be included within this analysis are HFV, HCLV, CH4V, NOV, CO2V, H2OV, NO2V, O3V, and CSSMAG. The system noise trend should try and account for solar variations (see below) and pointer tracker noise (see below).

Maximum Signal

Maximum V signal levels should be trended during each sunset event autobalance sequence while FSSTOP = 126 ± 2. Channels that should be included within this analysis are HFV, HCLV, CH4V, NOV, CO2V, H2OV, NO2V, O3V, and CSSMAG. Variations in these signals may be caused by solar variations, detector response changes, temperature effects, or contamination. The HALOE Science Team should be responsible for correlating different effects, and the HALOE Flight Operations Team should monitor and notify the science team of any unexpected changes.

Trend plots will be developed to show the mean, minimum value, and the maximum value of the V signal on the y-axis and the orbit number, the day number, or the beta precession on the x-axis.

Pointer/Tracker Noise

Pointer tracker induced system noise can be inferred by analyzing data obtained during the FOV calibration. During the FOV calibration, the pointer tracker system is placed in telemetry only mode (TLM) so the Sun can scan across the instrument field of views. This data will not contain the pointer/tracker systems input to the overall system noise budget. By examining data with and without the pointer/tracker system operating, the noise contribution of the pointer tracker system should be obtained.

Exo-Atmospheric Drift Rate

The slope of the R channel modulation ($\Delta R/R$) with $\Delta R'$ enhancement should be monitored during exo-atmospheric operation. The slope, which should give a good indication of instrument drift characteristics, should be trend plotted with the slope value on the y-axis and the orbit number, the day number, or the beta precession on the x-axis. Separate plots will be created for both sunset and sunrise events.

System Gains

The gain calibration is used to infer system ΔR, $\Delta R'$, and ΔV gains. These quantities, along with the balance voltage, crosstalk, and the mainframe average temperature (MFAVT), shall be trended on a continuous basis. The balance point should be monitored closely, since variations in the balance voltage will change the DAC values used during the gain calibration relative time sequence (RTS). Trend plotting capabilities will be developed so separate plots of the ΔR gain, the $\Delta R'$ gain, the ΔV gain, the balance voltage, and the MFAVT can be plotted on the y-axis and the orbit number, the day number, and the beta precession can be plotted on the x-axis.

Boresight Angles

The boresight calibration will be performed to determine the science telescope to Sun sensor alignment. Data obtained during the boresight calibration will be analyzed by the pointer/tracker subsystem manager or his designate.

FOV ΔV Mismatch

The difference between the maximum ΔV and minimum ΔV as the FOV scans the solar edge during the FOV calibration will be trended for each gas correlation channel.

FOV Mismatch

Data obtained during the FOV calibration will be analyzed to determine the difference between the vacuum channel and gas channel IFOV's in arc seconds.

Off-Axis Rejection

The ratio of V at two IFOV's past the solar limb to V at the Sun center will be calculated during each sunset and sunrise solar scan sequence. The ratios will be plotted as a function of orbit number.

Cal Wheel Neutral Density Transmittance

The standard deviation (in percent) of transmittance values will be calculated for each of the cal wheel ND filters. The raw transmittance values will be plotted as a function of orbit number along with the percentage standard deviation for each filter.

Cal Wheel Induced Exo-Atmospheric Modulation

Cal wheel induced modulation will be trended for each gas cell port and neutral density filter to monitor instrument stability. Modulation values should be obtained from a frozen version of the HALOE science data processing software. The modulation values for each port will be plotted as a function of orbit number. (optional) The HALOE Flight Operations Team will trend $\Delta V/V$or modulation.

*Blackbody Stability**

Blackbody stability will be trended to verify that the blackbody is stable with time and temperature. The blackbody resistance, BBR, will be trended during stow, during sunset events, and during sunrise events. If the blackbody exhibits any temperature sensitivity, a correlative analysis should be performed to verify that any temperature dependance remains constant.

*Bit Noise Remnants**

Telemetry while the instrument is in stow and during stable (exo-atmospheric) times should be examined periodically for bit noise remnants. The most efficient and sensitive method of evaluating bit noise will require that the power spectral density of the channel in question be calculated and examined. The channels to be monitored and the frequency of monitoring include H2OBI and TBD.

*Pointer Tracker Check**

Data obtained during the pointer/tracker check at the end of sunrise solar scans should be reduced and monitored to ensure the pointer/tracker subsystem is functioning correctly. Trend plots of the fine Sun sensor extent (FSSBOT-FSSTOP) versus the azimuth offset (CSSAZ) should include weekly, beta precession cycle, and yearly averages.

*Fine Sun Sensor Extent**

The fine Sun sensor extent (FSSBOT - FSSTOP) should be monitored during the sunset autobalance sequence and during sunset and sunrise cal wheel cycles. Extent data should be plotted as a function of time and limit checking should alert the HALOE Flight Operations Team if the extent is below 116 diodes.

*Sun Sensor Contamination**

Sun sensor contamination/performance should be monitored by examining parameters VPEAK (fine Sun sensor) and CSSMAG (coarse Sun sensor) while the instrument is tracking the Sun exo-atmospherically. VPEAK and CSSMAG values should be plotted as a continuous time series.

*Stow Position Check**

The stow position of the instrument should be monitored to ensure that the instrument is moving to the correct stow position. The stow position check can be made by comparing the actual stow position with the programmed stow position. Variations in stow position by more than a few counts should give some indication of how many times the instrument has lost track of the Sun and slewed to a gimbal soft limit. Stow position data should be presented as the difference between programmed and actual stow position versus time. Separate plots for the azimuth axis and the elevation axis will be provided.

*Azimuth Track Error**

The relative coarse azimuth position, CSSAZ, will be monitored during autobalance and cal wheel cycles to ensure that the track error is within expected tolerances. Limit checking software will warn the HALOE Flight Operations Team any time the track error during these modes exceeds ± 150mV.

*Elevation Track Error**

The relative fine sun sensor elevation position, FSSTOP, will be monitored during autobalance and cal wheel cycles to ensure that the track error is within expected tolerances. Limit checking software will also alert the HALOE Flight Operations Team any time that the FSSTOP is less than 123 diodes or greater than 128 diodes.

*Solar Acquisition Check**

The difference between the GSFC Flight Dynamics Facility (FDF) planning aid calculated initial position and (l) the actual instrument initial position which is denoted by transition to Mode 4, and (2) the sunset/sunrise initial position which is denoted by transition to Mode 3, shall be trended on a beta precession cycle. Variations greater than 0.5 degree (5 counts) (TBR) in azimuth and 0.5 degree (47 counts) shall be flagged as out of limit conditions.

*Fine Sun Sensor Diode Check**

Fine Sun sensor correlation parameters TCOR and BCOR shall be both trended and limit checked to verify that the fine Sun sensor diodes are functioning correctly. A limit violation shall be logged if TCOR does not equal 12 and BCOR does not equal zero when the instrument is performing an autobalance or cal wheel cycle.

*V/R Ratio**

The V signal/R signal ratio while the instrument is pointed at the middle of the solar disk (FSSTOP = 82 ± 5) shall monitored and plotted as a continuous time series.

*IFOV Extent**

Data from the FOV calibration shall be used to calculate the width (10% - 90%) of the IFOV in arcseconds. Width data obtained during the calibration will be plotted and maintained as a continuous time series.

Gimbal Slew Rate

The azimuth and elevation slew rates will be monitored during slew to initial position (Mode 2) and during slew to stow (Mode 7). Data slew rate measurements shall be taken 10 seconds after the slew has begun through 10 seconds from the slew end. Plots of azimuth and elevation slew rates as a function of time shall be maintained.

7.5 Level 1 Data Validation

The corrected and calibrated signals derived at the Level 1 stage can be used to calculate modulation and atmospheric transmittance signals which represent the most fundamental science quantities. As noted in Section 5.0, it is important to evaluate these data before retrieval methods are applied which tend to amplify errors. The first level evaluation is to determine that the signals fall within proper bounds. This will provide a check on the data processing steps up to Level 1. Transmittances will be checked to ensure that they start at a value of 1.0 for high altitudes and then fall to reasonable levels (based on climatology and other data) at low altitudes. The modulation values will be analyzed to ensure that they begin at the noise level at high altitude and then rise to levels that fall within the expected range calculated using climatology. Any deviations outside this range will be noted and studied further to determine the validity of the results. To aid these studies, hard-copy products will be produced each day for sunrise and sunset showing vertical profiles for each channel on the same page displaced horizontally. This will include four modulation channels and eight radiometer channels. A reference notebook will be produced for each channel for each year of operation.

Where tangent point overpass data exist, these correlative data will be used with the HALOE LIMTRAN forward model to calculate modulation and transmittance profiles for direct comparison with the measurements. Differences will be calculated versus altitude and statistics will be developed to identify any problems.

7.6 Level 2 Data Validation

The retrieved geophysical data will be validated in stages. The first order evaluation will be to determine if the results are reasonable, e.g. that the maximum O_3 mixing ratio does not exceed 12 ppmv, that H_2O levels are less than ≈ 7 ppmv in the stratosphere, that NO_2 values are less than 15 ppbv, or that CH_4 maximum values are less than about 1.7 ppmv. Again, to aid these studies, hard-copy mixing ratio and temperature profile products will be produced each day for each channel showing sunrise and sunset results on a single page. This will be done for temperature and the seven gases being observed.

A next step in the Level 2 validation will be to test measurement precision under quiescent conditions, e.g. in summer or the Tropics. The high latitudes are especially suited for this since the tangent point tracks overlap from one orbit to the next. In some cases, the sunrise and sunset occultations overlap and can be used to evaluate diurnal changes. This test will verify that sunset/sunrise differences are reasonable for diurnally variable gases and that little or no change is seen for the long-lived species. Plots of zonal mean profiles and the standard deviation about the mean will be made routinely for all channels in the Tropics and at high latitudes where overlap occurs under quiescent conditions. Plots of sunset/sunrise ratios will be made for all channels routinely whenever these tangent point tracks overlap.

The next level of validation is comparison with ground, balloon, rocket, or aircraft data, where possible. The coincidence criteria for an overpass acceptance are described in Section 7.8.1. Plots will be made of HALOE data overlaid with all profiles of a given specie at a given site. Also displayed will be the mean differences in the vertical direction between HALOE and other data and the standard deviation of the differences among the profiles. Where aircraft data exist in column amount form, HALOE column amounts for that gas will be calculated and compared. Total ozone above the lowest HALOE altitude will be routinely produced and compared with ground-based data for all stations in the Dobson network whenever a HALOE overpass comes with 500 km or 1,000 km of that site. The locations of Dobson stations are given in Appendix C.

As an attempt to better define atmospheric variability around standard balloon, rocket, or ground sounding sites, and to facilitate comparisons, HALOE data will be selected and stored in a designated file whenever an overpass occurs within 500 km or 1,000 km of these sites. This will also facilitate comparisons with correlative data at these locations. The data base will include all stations being used in the Network for Detection of Stratospheric Change. These sites are identified in Table 7-7.

7.7 Level 3 Data Validation

The first stage of Level 3 studies, like Level 2 validation, will be to evaluate the data to determine if results are reasonable. Zonal mean profile shapes over selected latitude ranges (low, mid, and high latitudes) will be generated and compared with past observations from LIMS, SAGE, SAGE II, and SME, climatology, and model results. In addition, these same data sources will be used to compare with HALOE zonal mean pressure versus latitude cross sections. Any significant deviations will be noted and evaluated further for validity. Plots will be made of zonal mean cross sections for past observations which cover the same averaging intervals and time periods as the HALOE data. In addition, difference plots between HALOE and other data will be generated to allow quick identification of regions of largest differences and to understand how the differences vary with latitude.

The next step will be to use Level 3 pressure versus longitude cross sections as a way to interpolate HALOE data on a given day to the locations of correlative measurement sites in order to improve coincidence. This also brings in other errors, and the process must be done carefully.

Table 7-7. **Selected Ground Sounding Sites**

Name	Latitude	Longitude	Comment
Thule, Greenland	77.3N	290.7E	NDSC
Resolute, Canada	74.4N	265.4E	NDSC
Observatory Haute-Provence, France	45N	5E	NDSC, Balloon launch site
Jungfrajoch, Switzerland	47N	8E	NDSC
Ft. Sumner, New Mexico	34.5N	255.7E	Balloon launch site
Table Mountain, California	34.3N	242.3E	Ground site
Palestine, Texas	31.7N	264.4E	Balloon launch site
Mauna Loa, Hawaii	19.5N	204.4E	NDSC
Madras, India	13.1N	80.2E	
Kuala Lumpur, Malaysia	3.1N	104.4E	
Quito, Ecuador	0.1S	281.7E	
Natal, Brazil	5.5S 5.52S	324.9E 324.8E	
Darwin, Australia	12.2S	130.4E	
Lauder, New Zealand	45S	169.4E	NDSC
Dumont D'Urville, Antarctica	66.4S	140E	NDSC
Halley Bay, Antarctica	76S	333E	
McMurdo, Antarctica	78S	167E	

7.8 Data Intercomparisons

7.8.1 Guidelines

Ideally, a correlative measurement (CM) would provide simultaneous data in the same atmospheric volume element sensed by the HALOE field of view at the tangent ray height. For practical reasons, however, such an exact coincidence is not likely to occur. The fact that HALOE obtains only sunrise and sunset measurements will further complicate attempts to obtain near coincidence in space and time. A realistic requirement is that correlative data be collected as close in space and time to the HALOE measurements as is possible. To be of most use, the horizontal distance between the HALOE tangent point and the position of the CM must be small compared to the length scale over which the constituent of interest varies. Longitudinal variations arise from two principal causes. The first is a photochemically driven diurnal variation which affects species whose lifetimes are short compared to 1 day. Only three HALOE gases are influenced this way; NO and NO_2 at all altitudes observed, and O_3 above 55 or 60 km. The second type of longitudinal variation is associated with the planetary scale waves having wavenumbers one and two. The longitudinal distance from the maximum to minimum in a wavenumber two disturbance at 40 degrees latitude is approximately 7.65 x 10^3 km. Corresponding values at the Equator and 60 degrees are 1.00×10^4 km and 5.00×10^3 km. A reasonable longitudinal distance over which variability may be assumed small is 10 percent of these lengths. In all cases, a longitudinal separation of 500 km is acceptable.

From the above information, the following spatial coincidence criteria can be defined. As a desired target, the HALOE tangent point should lie within a 150 km radius of the CM site, while an acceptable coincidence is one where the HALOE observations lie within 500 km of the CM sounding. At middle and low latitudes, measurements which lie within 350 km in the north-south direction, but which are separated by 600 km measured east-west, should still be useful as a test of HALOE operations. The temporal coincidence goal is to compare measurements taken within 1 hour of one another, while an acceptable coincidence is when HALOE and CM data are taken no more than 3 hours apart. In cases where HALOE species undergo diurnal variations (e.g. stratospheric NO and NO_2, mesospheric O_3), direct comparisons can only be made with data collected at sunrise or sunset, or corrections must be developed to refer the occultation results to local times appropriate to the correlative data. Estimated uncertainties resulting from the lack of simultaneity must be incorporated into the error bars when making these intercomparisons.

The correlative measurements effort must allow evaluation of instrument performance over a broad range of observing conditions (e.g. duration of an occultation, apparent motion of the Sun during an observation, magnitudes of the mixing ratios observed, and so on). The correlative measurements data base, therefore, should include data at low, middle, and high latitudes during all seasons. As a minimum, measurements in the Northern Hemisphere and in the winter and summer are adequate to observe a representative atmospheric variability. To obtain comparisons over a variety of conditions, however, it is desirable that the correlative measurement frequency provide profiles of each HALOE gas every 3 months. Acquisition of such a large quantity of independent data is not considered an absolute requirement, but would be very valuable. To assist in the detection of time-dependent changes in instrument sensitivity, correlative measurements must be performed over the entire duration of the UARS mission.

7.8.2 Intercomparison Data Base, Software, Approach, and File Locations

Validation Software

The software written for the validation procedure allows comparisons to be made using HALOE retrieved profiles and data from other data sources. The software is separated into three main sections: SELECTION, COMPARISON, and DISPLAY. The three sections are tied together using the operating system, which allows basic commands to be menu driven. Deviations from a simple 1-2-3 session can be invoked by using files created previously or by changing default file names when prompted. Selection and processing of data are handled with FORTRAN. The display of data uses the Interactive Data Language (IDL). By porting the statistics output file elsewhere, however, any graphics package may be used.

The validation software and Inter-Comparison Data Base (ICDB) is located on tho HALOE RAC data disk DUC4. A portion of this disk has been allocated for use in the validation process. The directory DUC4:[VALID], has been divided into three sections: SOURCE, DATA, and INFO. The directory will keep the FORTRAN codes, the ICDB data sets, and the specific commands needed to use the software and access the data. Logical names will be established to reference the codes and data.

This document and information on how to use the software (help.doc) can be found in: "HALOE::DUC4:[VALID.INFO]" and in the three subdirectories:

"[VALID.INFO.SOURCE.SELECT]select.doc",
"[VALID.INFO.SOURCE.COMPARE]compare.doc",
"[VALID.INFO.SOURCE.DISPLAY]display.doc".

Intercomparison Data Base

Figure 7-1 shows a block diagram of the ICDB sources and is a basic overview of the comparison procedure. The HALOE data which can be used come from data levels one, two, or three. The primary element in the validation data base is the climatology developed for UARS by Seals (1991). This gridded data set is composed of zonal monthly mean profiles for 12 months with a 10-degree spacing in latitude from -80 to 80, and 3 km spacing in the vertical from Z = 10.5 to 121.5. Each of the primary and interfering gases are included in the climatology. Access to the data will allow selection of data with reference to UARS day, latitude, local time, and molecule. As the climatology was derived from both measured and modeled values, the source of the output profile will be included in any comparisons.

Previous satellite data which are contained in the data base include: LIMS (H_2O, NO_2, O_3, T); SAMS (CH_4, N_2O, T); SBUV (O_3); ATMOS (H_2O, CH_4, HF, HCl, NO, NO_2, O_3); and SAGE II (O_3, H_2O, NO_2). Results from modeled chemistry will be available from the Solomon and Garcia 2-D and the NASA-LaRC Grose 3-D GCM/chemistry models. Previously measured values from balloon- and ground-based experiments will be grouped together into files corresponding to each molecule, and then by latitude band (low, middle and high latitudes). Correlative measurements specific to the UARS Project will be added to the data base as they become available.

Selection and Access of Data

Generally, access to the data will key on time and location as opposed to UARS orbit number or event number for the day. Each of the data sets are accessed by referencing the location and time of the data (obviously limited in some cases). For example, HALOE Level 2 data can be accessed through the SELECTION menu of the software. The locations and date/time are provided, and the user is prompted as to whether the data should be saved for later processing. After selecting and saving the HALOE data, correlative profiles can be accessed and saved in a similar manner.

Comparison

At this stage, the comparison program PSTATS can be run using the data that were saved. (For reference, see Fig. 7-1) Input to PSTATS is controlled with an ASCII file which is interactively updated with every comparison . This control file records the input file names, processing options, and user comments. Three sets of multiple profiles can be compared at one time. Two sets from HALOE versus one from the ICDB, say correlative. Each of the profiles are interpolated onto either a standard (HALOE versus HALOE) or correlative (HALOE versus correlative) pressure level, and differenced. The mean and RMS differences and estimates of the standard deviation of the means are computed on standard pressure levels. Column amount of gases are also calculated from top down at each of the standard pressure levels. Along with the input profiles, all of the calculated values are saved on disk.

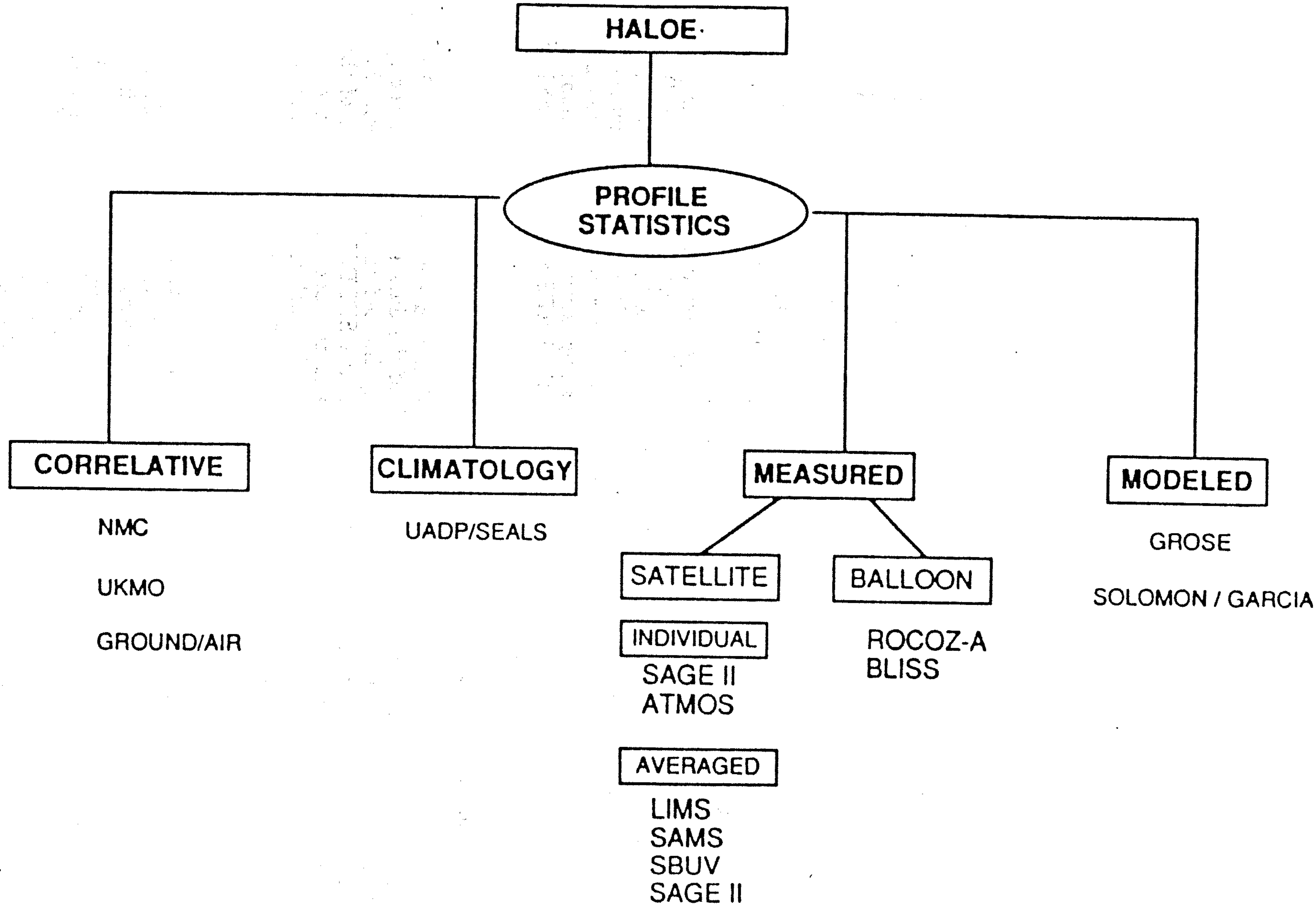


Figure 7-1. HALOE Intercomparison Data Base Sources

Graphical Display

There are basically two options in this category. The first is simply a display of the profiles and basic mean and standard deviation statistics from a set of selected HALOE profiles. HALOE signals or retrieved geophysical parameters can be displayed as a function of the original pressure levels. As an option, the profiles can be interpolated to a standard pressure level grid, and the mean and standard deviation at each level can be plotted alongside.

The second option available is the display of the statistics file created with the comparison program PSTATS. This allows the plotting of each profile used in the comparisons and the differences, as well as final statistics on the set of profiles. This can be as simple as viewing one HALOE temperature profile compared with another orbit or it could involve two sets of HALOE values and a set of correlative profiles. In this latter case, one can either view each of the profiles and their respective differences and, in turn, the final statistics, or skip ahead and view only the final statistics.

User options at this stage include changing the range or style (log or linear) on the X and Y axes, title, plotting device (VT240, X, Postscript, TEK, monochrome, or color) or location of the legend.

7.8.3 *Correlative Measurements, NMC, British Met Office, NDSC, and Dobson Data*

An extensive set of gases will be measured as part of the UARS correlative measurement program. These measurements are described in detail in a report by Hypes (1991). An overview of planned correlative measurements from the report, the expected altitude ranges of the measurements, the planned locations of the measurements, and the schedule are included in Appendix B. As can be seen, there are many observations which will be of direct use in HALOE data validation. In addition, the National Meteorological Center (NMC) and British Met Office are providing temperature versus pressure data which will be placed in the CDHF daily. The data set is accompanied by software which allows interpolation to any desired latitude/longitude point by a subroutine call. Finally, the NDSC data are being stored by the NMC and will be electronically accessible by the UARS network. These measurements include millimeter wave soundings of O_3, H_2O, and ClO vertical profiles; lidar soundings of temperature O_3, and aerosols; UV-visible sounding of NO_2, NO_3, O_3, and OClO column amounts; and infrared measurements of the column amounts of many IR-active gases using Fourier transform interferometry.

7.8.4 *Other UARS Measurements*

Several UARS experiments are measuring some of the same parameters being measured by HALOE. MLS will measure the vertical temperature, O_3, and H_2O profiles; CLAES will measure temperature, O_3, NO, NO_2, H_2O, CH_4, and HCl; and ISAMS will observe temperature, O_3, NO, NO_2, H_2O, and CH_4. This provides a good satellite data base for intercomparison whenever the HALOE sunrise or sunset tangent points overlap the other measurement locations and times. This will usually occur only at high latitudes at certain times of year. It would still be a useful intercomparison, however, even if the time differences are several orbits or several days. The comparison in this case would be more for qualitative than quantitative validation studies.

7.8.5 Targets of Opportunity

There will be other intercomparison opportunities in addition to the planned UARS correlative measurements. Unplanned balloon flights, rocket soundings, ground measurements, or aircraft observations will be occurring. The plan to store all HALOE data occurring over standard launch sites will facilitate intercomparisons. The HALOE Team will be on the alert throughout the mission for such opportunities. In addition, the planned Space Shuttle ATLAS Mission will provide excellent intercomparison data. The flight of the ATMOS Experiment in 1992 is an ideal comparison data set since ATMOS is also a solar occultation experiment and measures high resolution atmospheric spectra using a Michelson interferometer with 0.01 cm^{-1} unapodized resolution. ATMOS measures all gases being observed by HALOE. Discussions have been held with the ATMOS P.I. on ATMOS measurement priorities that will be of most benefit to HALOE. Another ATLAS mission named CRISTA also will measure most HALOE parameters but using limb emission. CRISTA will fly on a later ATLAS mission in 1994. Preliminary discussions have also been held with the CRISTA P.I. to arrange for intercomparison with HALOE data.

7.8.6 Theoretical Investigator Interaction

Plans have been made to collaborate with Dr. William L. Grose on HALOE data validation using the Langley 3-D model to generate sunrise/sunset fields for comparison with HALOE results. The Langley model is a spectral model which transports chemical families, partitions the families, and includes representation of the formation of polar stratospheric clouds in the Antarctic and Arctic. This model will provide the zonal mean pressure versus latitude cross sections, pressure versus longitude cross sections, and vertical profiles for testing to see that the data are reasonable. In addition, arrangements have been made with A. James Miller of the NMC who will intercompare HALOE ozone products with NMC operational results.

7.9 Data Quality Attributes

Since HALOE data will be available to all UARS users almost immediately after collection, it is essential that some kind of quantitative descriptor variable be designated to characterize the data quality. This will hopefully minimize any confusion and time lost because of attempts to use data in scientific investigations that have known deficiencies or that are in an early stage of validation. The UARS Project has designated that the data quality attributes be stored as C*80 fields in the UARS catalogued file data base which provides summary information on quality of a data file. Five levels have been assigned to describe the status of data validation (see Table 7-8a), and four levels have been selected to describe the data quality in a file (Table 7-8b).

The first descriptor (0.q) represents the lowest state of validation checks. This designation would mean that the only checks performed are those done in production processing automatically by the software.

The next validation status level (1.q) indicates that a qualitative check has been performed, meaning the data fall within reasonable bounds. A designation at this level would mean that profile shapes, latitude cross sections, polar projections, sunset/sunrise differences, and temperature and mixing ratio levels have been checked to see that the values are reasonable. The next validation status level (2.q) would indicate that quantitative evaluation has occurred. An attribute designation at level (2.q) would mean that deviations from conventional data based on past observations or unusual model data differences have been studied in detail for validity, and error bars have been reviewed and updated. The cross-correlated (3.q) numerical assignment would mean that intercomparisons have been made with correlative data collected from ground-based, aircraft, balloon, rocket, or other UARS results and that differences between the data sets have been quantified and reconciled, or accepted and noted. The last level (4.q) designation means that the data are understood well enough and sufficiently characterized so that they can be published. It may be that if a file is to be assigned a level (4.1), for example, meaning publishable but of poor quality, an election to withhold publication would be made. At the very least, it would mean to the user that while some of the data in the file is good, much of it is poor, and the data should be used only with great caution and in close consultation with the HALOE P.I. Interim description variables will be placed in the summary file in the beginning of the mission and gradually upgraded as the HALOE Science Team proceeds in the validation process. The final designations will be made by Science Team concensus achieved through quarterly meetings and detailed data review and discussion.

Table 7-8a. UARS Data Validation Status Definitions

Data Validation Level	Numerical Indicators
Unverified	0.q
Qualitative evaluation	1.q
Quantitative evaluation	2.q
Cross-correlated	3.q
Publishable	4.q

Table 7-8b. UARS Data File Quality Variable q

Numerical Indicator	File Quality Level	Fraction of Good Data in the File
1	Very good	98 - 100%
2	Good	75 - 98%
3	Fair	50 - 75%
4	Poor	< 50%

8.0 IMPLEMENTATION

8.1 Management

The HALOE data validation effort will be managed by the HALOE Principal Investigator. The validation will be implemented by the HALOE Science Team, with the support of the Langley Research Center software/science support team. A member of the Langley team will be assigned to work directly with a member of the Science Team and provide all necessary software support, data file preparation, plotting, and latest instrument/spacecraft information relevant to the validation effort. Preliminary assignments are outlined in Section 8.3. The Science Team will meet at 3-month intervals to review progress, discuss problems, and set the course for future activities.

8.2 Schedule

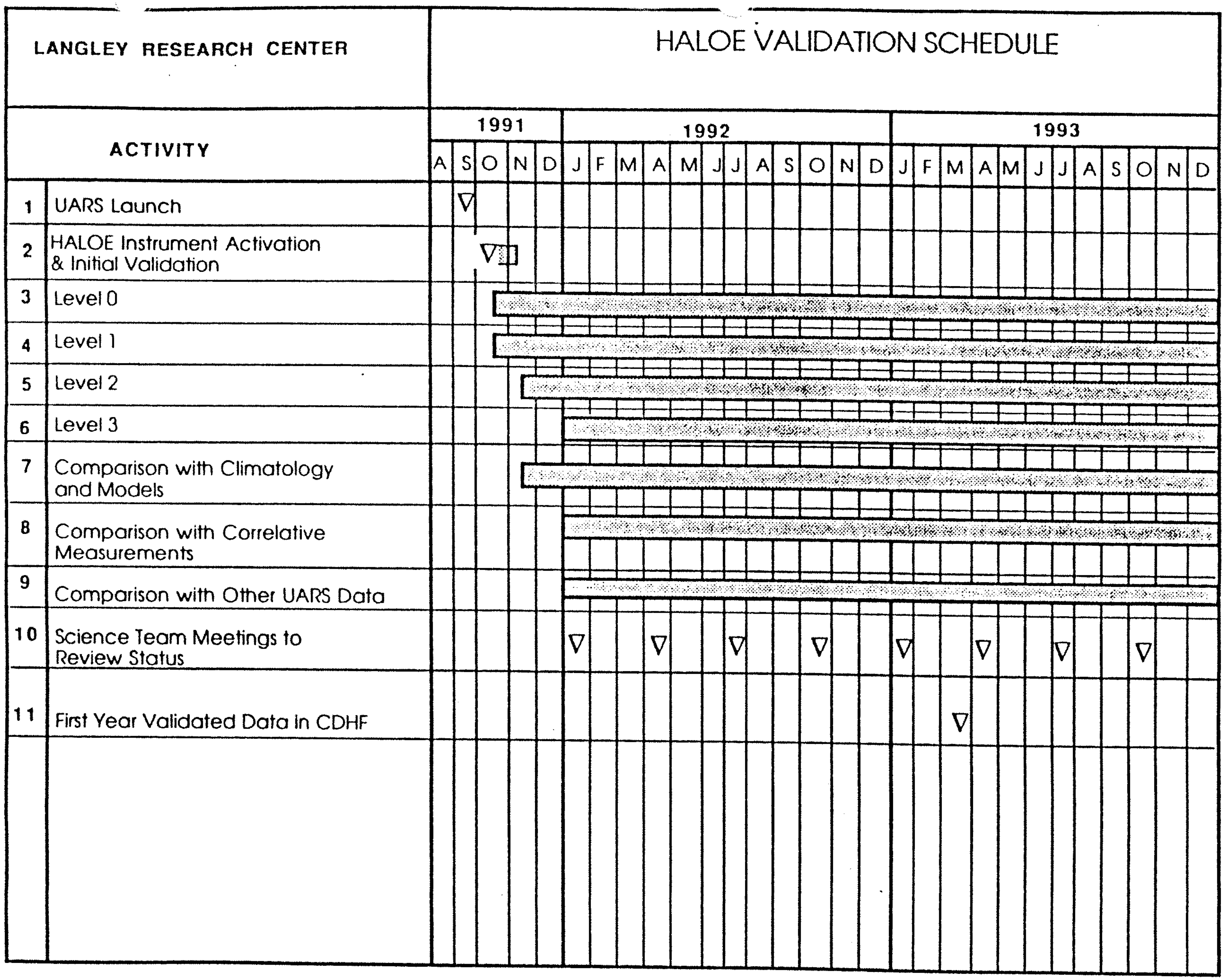
The validation schedule is given in Figure 8-1.

8.3 Personnel Assignments

The Level 0 validation effort will be concentrated at Langley with primary responsibility assigned to John G. Wells, supported by Donald R. Richardson. Preliminary assignments for the other products are given in Table 8-1.

Table 8-1. Preliminary Validation Assignments

Activity	Science Team Responsibility	Langley Support Scientist Responsibility
Level 1		
HCl	Russell	Beaver
HF	Russell	Deaver
CH_4	Park	Haggard
NO	Gordley	Beaver
H_2O	Drayson	McInerney
NO_2	Drayson	Stone
O_3	Drayson	McInerney
T(P)	Drayson	Stone
Level 2, 3AT, 3B		
HCl	Russell, Tuck	Beaver
HF	Cicerone, Russell	Deaver
CH_4	Park	Haggard
NO	Frederick	Beaver
H_2O	Harries, Russell	McInerney
NO_2	Gordley	Stone
O_3	Crutzen	McInerney
T(P)	Drayson	Stone


LANGLEY RESEARCH CENTER
HALOE VALIDATION SCHEDULE
ACTIVITY
1991
1992
1993
A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
1 UARS Launch
2 HALOE Instrument Activation & Initial Validation
3 Level 0
4 Level 1
5 Level 2
6 Level 3
7 Comparison with Climatology and Models
8 Comparison with Correlative Measurements
9 Comparison with Other UARS Data
10 Science Team Meetings to Review Status
11 First Year Validated Data In CDHF

Appendix A

HALOE Modes Document

by

Edward M. Sullivan

June 1991

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1.0 INTRODUCTION

HALOE measures the concentration profiles of the atmospheric trace gases HF, HCl, CH_4, NO, NO_2, O_3, and H_2O. Broadband absorption in the CO_2 2-7 μm band will be measured to determine the atmospheric temperature versus pressure profile associated with the trace gas profiles. Gas filter correlation radiometry is used to measure HF, HCl, CH_4, and NO and broadband filter radiometry to measure NO_2, O_3, H_2O, and CO_2. Science data is obtained over the altitude range of 0 to 150 km.

Since HALOE takes data during solar occultation events, it follows that trace gas profiles are measured twice per orbit, i.e., during sunrise and sunset as seen by UARS. The HALOE Principal Investigator has set the goal of obtaining atmospheric concentration profile data for every sunrise and sunset event between the completion of the HALOE transition to routine operations and the end of the UARS mission.

HALOE, operating in conjunction with the UARS computer system, has the capability to perform at least four different sunrise sequences and two different sunset sequences. One sunrise and one sunset sequence are controlled entirely by the HALOE microprocessor. The remaining sequences combine control by the HALOE microprocessor with control by ATC-initiated RTS commands issued by the UARS computer system. This document provides an overview of these sequences and the data-taking steps contained in each.

2.0 SUNRISE OPERATIONS

Sunrise operations begin with the HALOE instrument in the "night" stow position and a set of sunrise conditions stored in the appropriate memory registers . At time *SC_SUNRISTAN* - Δt, the UARS OBC issues an ATC which instructs HALOE to initiate the slew which starts the sunrise event. The time *SC_SUNRISTAN* is determined from the planning aids as the time when the Sun will first be visible to HALOE; Δt is a time increment which allows for the time to slew from the stow position to the sunrise solar acquisition AZ and EL, plus a TBD second margin to ensure that HALOE is correctly positioned before *SC_SUNRISTAN*.

After acquisition, the first portion of the sunrise event is the science data period. This period begins when the solar energy reaching the Sun sensor exceeds a predefined threshold and the sun sensor initiates tracking of the solar disc. Solar track continues throughout the science data period.

The sunrise science data period ends when the elevation angle reaches a predefined value. This angle is currently set in the HALOE memory at -20.5 degrees, which corresponds to a tangent point altitude of 150 km. At this altitude, the HALOE line-of-sight to the Sun should be well above the sensible atmosphere so that the measured data no longer contain any atmospheric effects. If atmospheric effects should persist to higher altitudes, the science data period can

After the science data period, the HALOE instrument performs one of the four sunrise health and calibration sequences described in Section 4.1. Each sequence ends with a command to slew to the "day" stow position. The sunrise event ends when the instrument reaches a "day" stow and the appropriate memory registers are set for sunset conditions.

3.0 SUNSET OPERATIONS

Sunset operations begin with the HALOE instrument in the "day" stow position and the appropriate internal memory registers set to indicate that the next event is a sunset. At time *SC_TAN450SEC* - Δt, the UARS OBC issues an ATC which instructs HALOE to initiate the slew which starts the sunset event. The time *SC_TAN450SEC* is given by the planning aids and is defined as a time 7-1/2 minutes before the time when the setting Sun is at an elevation angle of -20.5 degrees (a tangent point altitude of 150 km); Δt is a time increment which allows for the time to slew from the stow position to the sunset solar AZ and EL, plus a TBD second margin to ensure that HALOE is correctly positioned before *SC_TAN450SEC*.

Solar acquisition occurs when the HALOE sun sensor has found the azimuthal center of the solar disc and initiated tracking of the specified point on the vertical center line of the disc. At this time, the HALOE instrument performs one of the two health and calibration sequences described in Section 4.2 These sequences require 7-1/2 minutes or less and, therefore, are complete before the setting Sun reaches an elevation angle of -20.5 degrees.

The sunset science data period begins at the end of the health and calibration sequence. During the science data period, the Sun sensor controls the biaxial gimbal system to track the Sun with the HALOE IFOV focused on a specified point on the solar disc. The science data period ends when the amount of solar radiation available to the HALOE Sun sensor becomes less than the threshold value required to track the Sun. At the end of the data period, the instrument is commanded to slew to the "night" stow position. The sunset event ends when the instrument reaches a "night" stow and the appropriate memory registers are set for sunrise conditions.

4.0 HEALTH AND CALIBRATION SEQUENCES

4.1 <u>Sunrise Sequences</u>

4.1.1 *Auto Sequence*

This sequence is performed entirely under control of the HALOE microprocessor. The sequence is initiated by a signal from the elevation gimbal which indicates that the solar elevation angle is at or above -20.5 degrees. The sequence contains the following three steps as shown in Fig. 1.

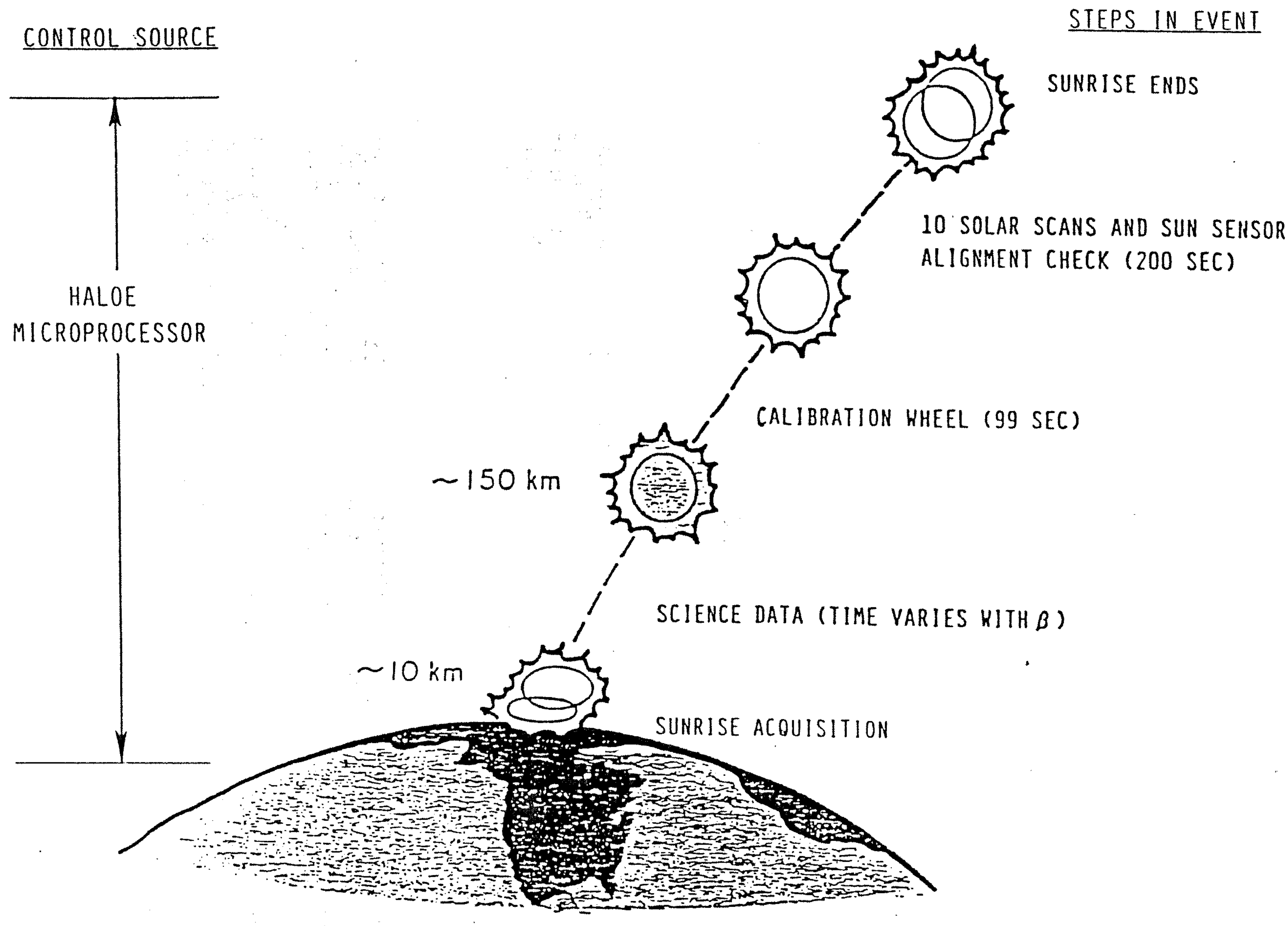


Figure 1. HALOE Sunrise Event with Auto Sequence

4.1.1.1 Calibration Wheel Rotation

The HALOE instrument contains an internal calibration wheel which consists of a flat disc with 12 holes spaced at 30-degree intervals on the circumference of a circle slightly less than the circumference of the wheel. Small gas cells containing known amounts of the gas species HALOE is measuring are mounted in eight of the holes. Neutral density filters of known transmittance are mounted in three of the holes. The last hole is the open hole through which the HALOE optical beam passes whenever the calibration wheel is not being rotated. Each revolution of this wheel while HALOE is tracking the exoatmospheric Sun will inject known absorption values into the HALOE data so that the stability of the instrument and the health of the HALOE gas cells can be verified.

This step in the sequence consists of one revolution of the calibration wheel. Since the wheel stops for approximately 7 seconds whenever one of the gas cells or filters is positioned in the HALOE optical beam, this step takes 99 seconds to complete.

4.1.1.2 Solar Scans

The HALOE data reduction requires a detailed knowledge of the solar limb darkening curve at the time of the science data. This is determined by forcing the HALOE IFOV to complete five solar scan cycles from 4 arcmin above the Sun to 4 arcmin below the Sun and return. These cycles take approximately 190 seconds to complete.

4.1.1.3 Sun Sensor Alignment Check

It is important to maintain a check on the alignment of the Sun sensor elements relative to each other. This is accomplished by shifting the IFOV focus point slightly to one side of the solar center line and then slightly to the other side of the solar center line. This check, which will be performed immediately after the solar scans at the end of most sunrise sequences takes approximately 10 seconds to complete.

4.1.2 *Gain Calibration Sequence*

This sequence is performed partially under control of the HALOE microprocessor and partially under control of an ATC-initiated relative time sequence (RTS) as shown in Fig. 2. The sequence is initiated by the ATC, which must be issued at a time after the science data period is complete. Since the ATC comes from the OBC-stored command load, it is important to have good planning aids to define the time at which the science data period ends. The first step in the sequence after the ATC is issued is the gain calibration check. At the end of the gain calibration, control is returned to the HALOE microprocessor to perform the solar scans and Sun sensor alignment test described in Sections 4.1.1.2 and 4.1.1.3.

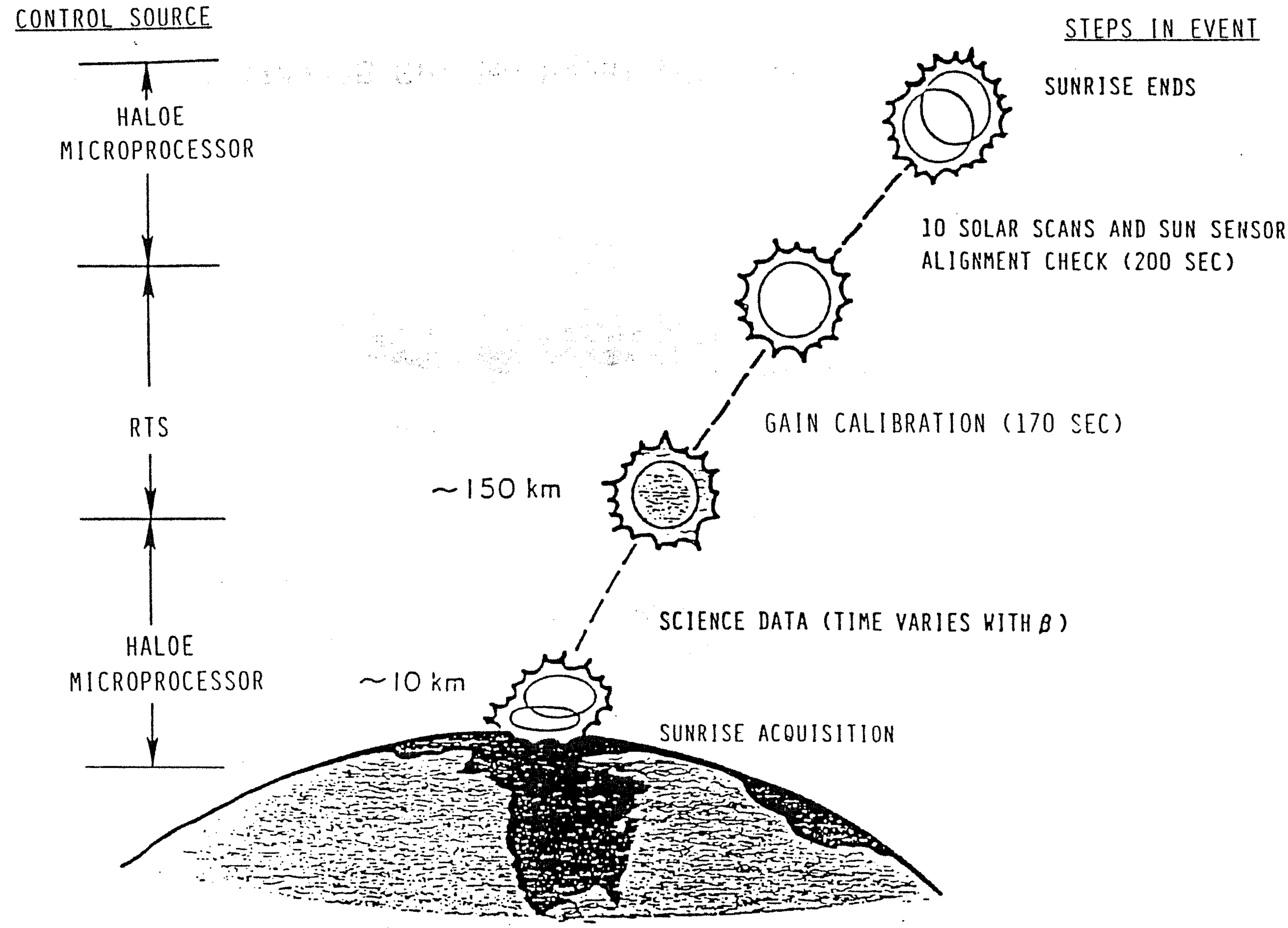


Figure 2. HALOE Sunrise Event with Gain Calibration Sequence

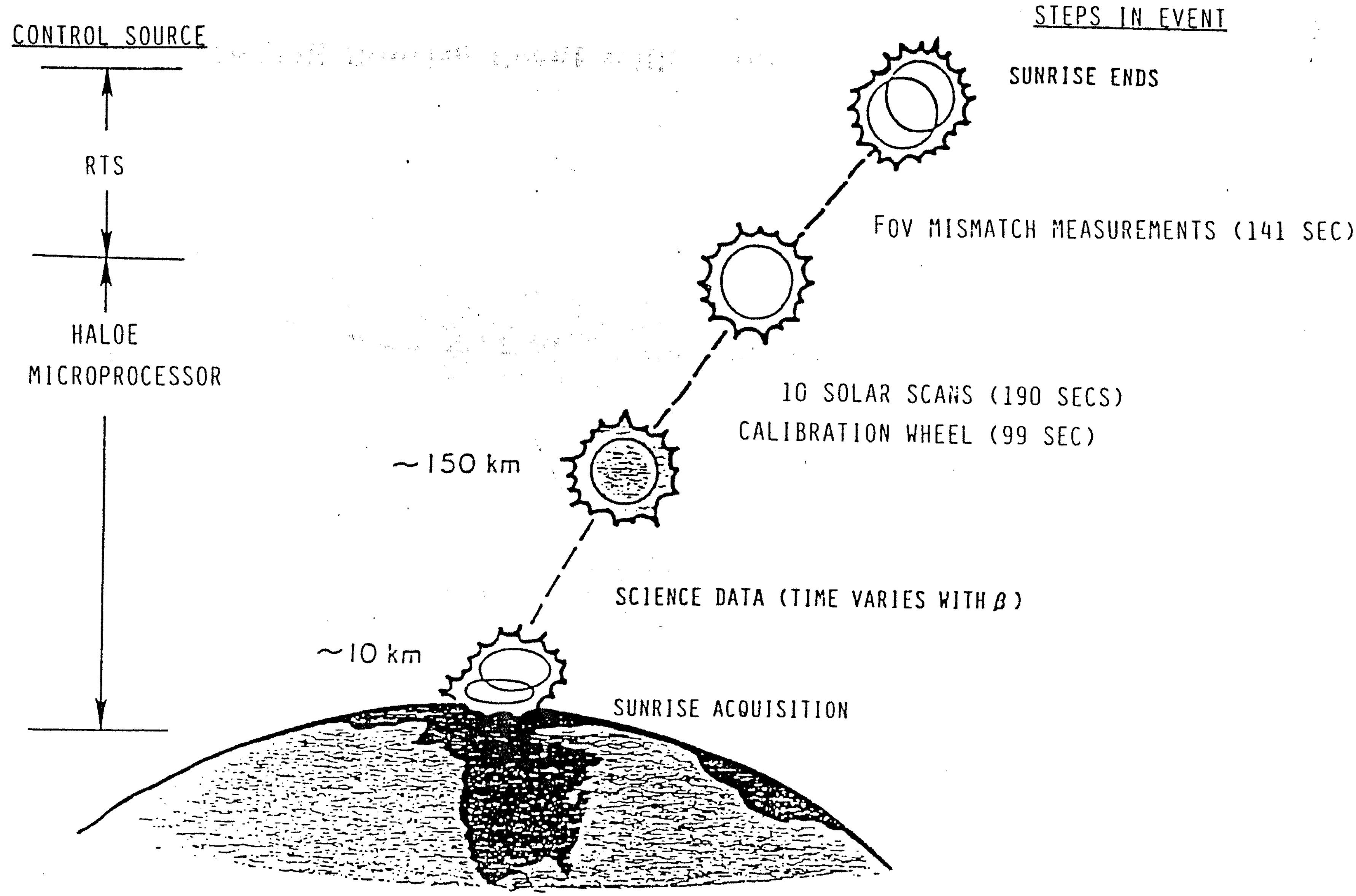


Figure 3. HALOE Sunrise Event with FOV Mismatch Sequence

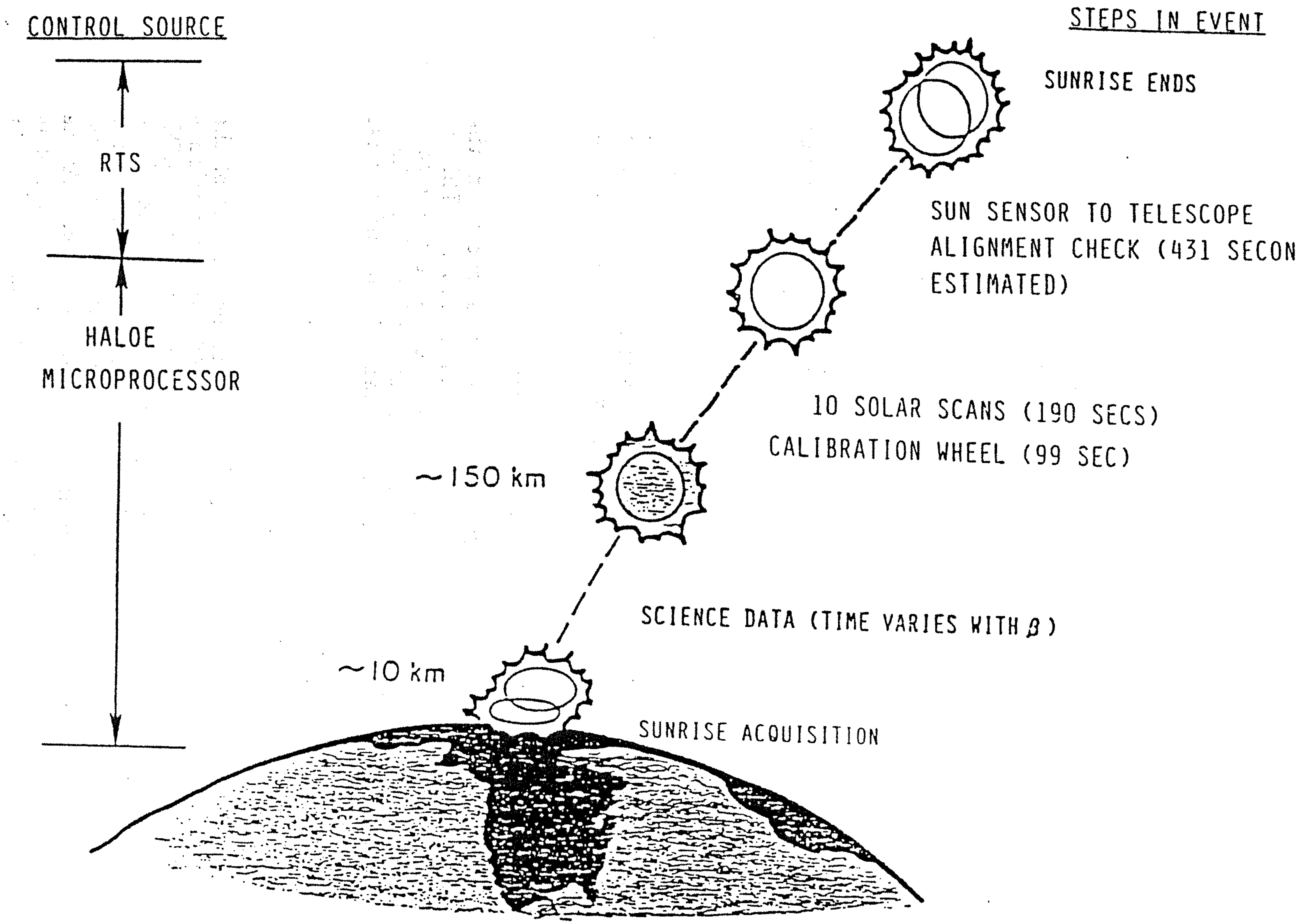


Figure 4. HALOE Sunrise Event with Boresight Alignment Sequence--Routine Operations.

4.1.1.1 Calibration Wheel Rotation

The HALOE instrument contains an internal calibration wheel which consists of a flat disc with 12 holes spaced at 30-degree intervals on the circumference of a circle slightly less than the circumference of the wheel. Small gas cells containing known amounts of the gas species HALOE is measuring are mounted in eight of the holes. Neutral density filters of known transmittance are mounted in three of the holes. The last hole is the open hole through which the HALOE optical beam passes whenever the calibration wheel is not being rotated. Each revolution of this wheel while HALOE is tracking the exoatmospheric Sun will inject known absorption values into the HALOE data so that the stability of the instrument and the health of the HALOE gas cells can be verified.

This step in the sequence consists of one revolution of the calibration wheel. Since the wheel stops for approximately 7 seconds whenever one of the gas cells or filters is positioned in the HALOE optical beam, this step takes 99 seconds to complete.

4.1.1.2 Solar Scans

The HALOE data reduction requires a detailed knowledge of the solar limb darkening curve at the time of the science data. This is determined by forcing the HALOE IFOV to complete five solar scan cycles from 4 arcmin above the Sun to 4 arcmin below the Sun and return. These cycles take approximately 190 seconds to complete.

4.1.1.3 Sun Sensor Alignment Check

It is important to maintain a check on the alignment of the Sun sensor elements relative to each other. This is accomplished by shifting the IFOV focus point slightly to one side of the solar center line and then slightly to the other side of the solar center line. This check, which will be performed immediately after the solar scans at the end of most sunrise sequences
takes approximately 10 seconds to complete.

4.1.2 *Gain Calibration Sequence*

This sequence is performed partially under control of the HALOE microprocessor and partially under control of an ATC-initiated relative time sequence (RTS) as shown in Fig. 2. The sequence is initiated by the ATC, which must be issued at a time after the science data period is complete. Since the ATC comes from the OBC-stored command load, it is important to have good planning aids to define the time at which the science data period ends. The first step in the sequence after the ATC is issued is the gain calibration check. At the end of the gain calibration, control is returned to the HALOE microprocessor to perform the solar scans and Sun sensor alignment test described in Sections 4.1.1.2 and 4.1.1.3.

or to at least ensure that the actual track point is known. The planned boresight alignment check will provide the data needed to meet the second objective and these data can be used to correct the Sun sensor pointing relative to the telescope so that the primary objective can be met.

4.1.5 *Solar Track (Drift) Sequence*

This sequence which consists of the single step, track the Sun from the time of acquisition until the end of the event, is entirely under the control of the HALOE microprocessor. For maximum effectiveness, this sequence should be performed during the sunrise which immediately follows the sunset solar track sequence in Section 4.2.3.

4.1.5.1 Solar Track

The data from the solar track sequence will permit an evaluation of the electronic noise characteristics and thermal stability of the entire HALOE instrument without the interference caused by solar scans, calibration wheel rotation, etc. The sequence will be performed during the transition to routine operations and at specified times thereafter to monitor the instrument performance as a function of mission time and ß angle.

4.2 Sunset Sequences

4.2.1 *Auto Sequence*

This sequence is performed entirely under control of the HALOE microprocessor. The sequence is initiated by a signal from the Sun sensor that the Sun has been acquired and solar tracking is in progress. The sequence shown in Fig. 6 contains an electronic balance step, plus solar scans (Section 4.1.1.2) and calibration wheel rotation (Section 4.1.1.1).

4.2.1.1 Balance

In order to enhance the accuracy of the gas correlation channel data, it is desirable that the science data period begin with these channels balanced so that the exoatmospheric signal difference between the vacuum and gas paths is $0 \pm 2 \times 10^{-5}$. This is accomplished through an internal algorithm which monitors the signal differences and adjusts the HALOE DAC settings until the desired balance is achieved. Depending on the degree of unbalance at the start of the sequence, this step can take as much as 60 seconds for completion.

4.2.2 *Gain Calibration Sequence*

This sequence is performed partially under control of the HALOE microprocessor and partially under control of an ATC-initiated RTS as shown in Fig. 7. The sequence is initiated by a signal from the Sun sensor that the Sun has been acquired and solar tracking is in progress. An ATC is issued at a time determined by the planning aids to initiate the gain calibration procedure RTS (Section 4.1.2.1). At the end of the RTS, control is returned to the microprocessor which has been preprogrammed to control the electronic balance (Section 4.2.1.1) and solar scans (Section 4.1.1.2) and omit the calibration wheel rotation which followed the solar scans in Section 4.2.1.

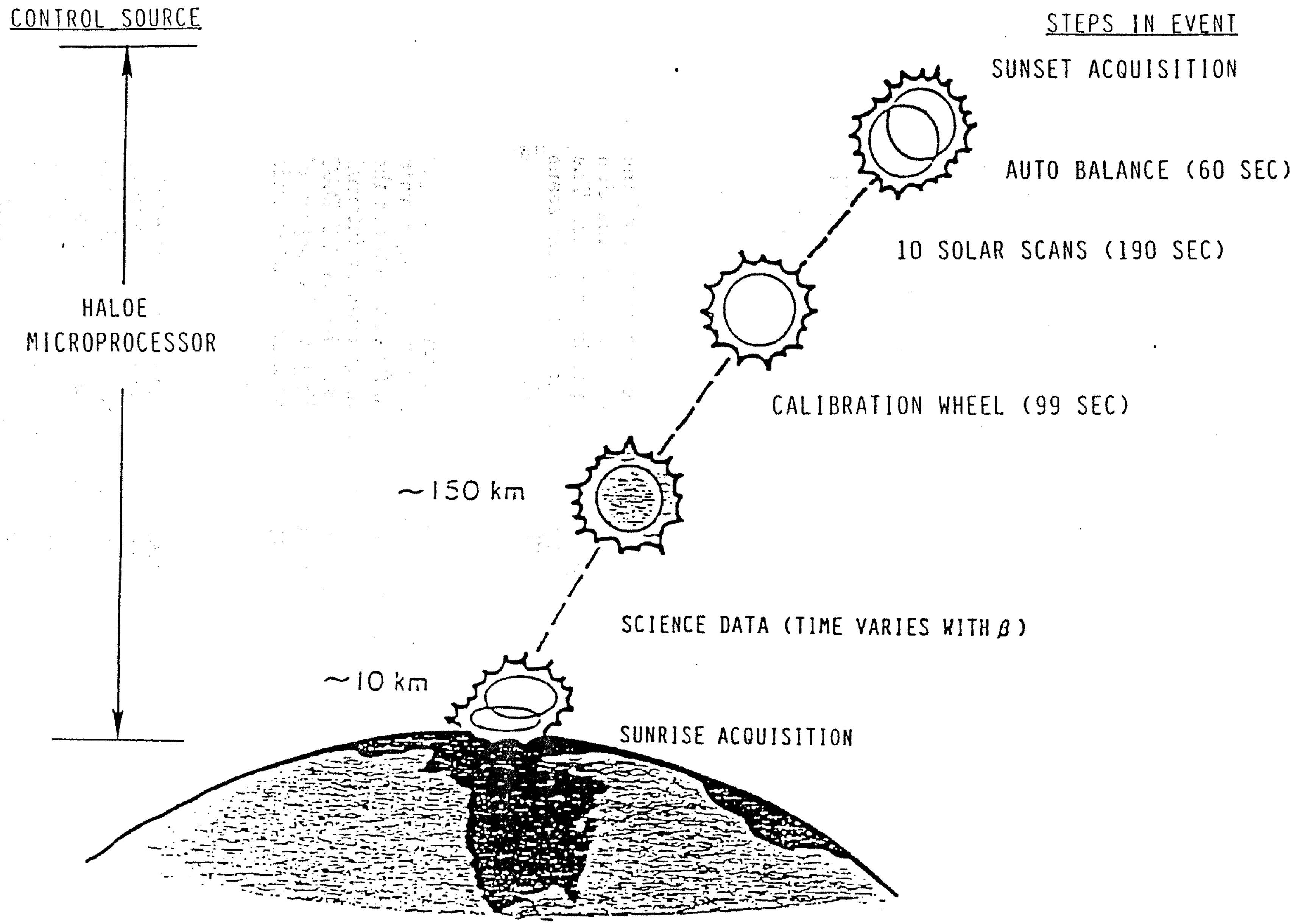


Figure 6. HALOE Sunset Event with Auto Sequence

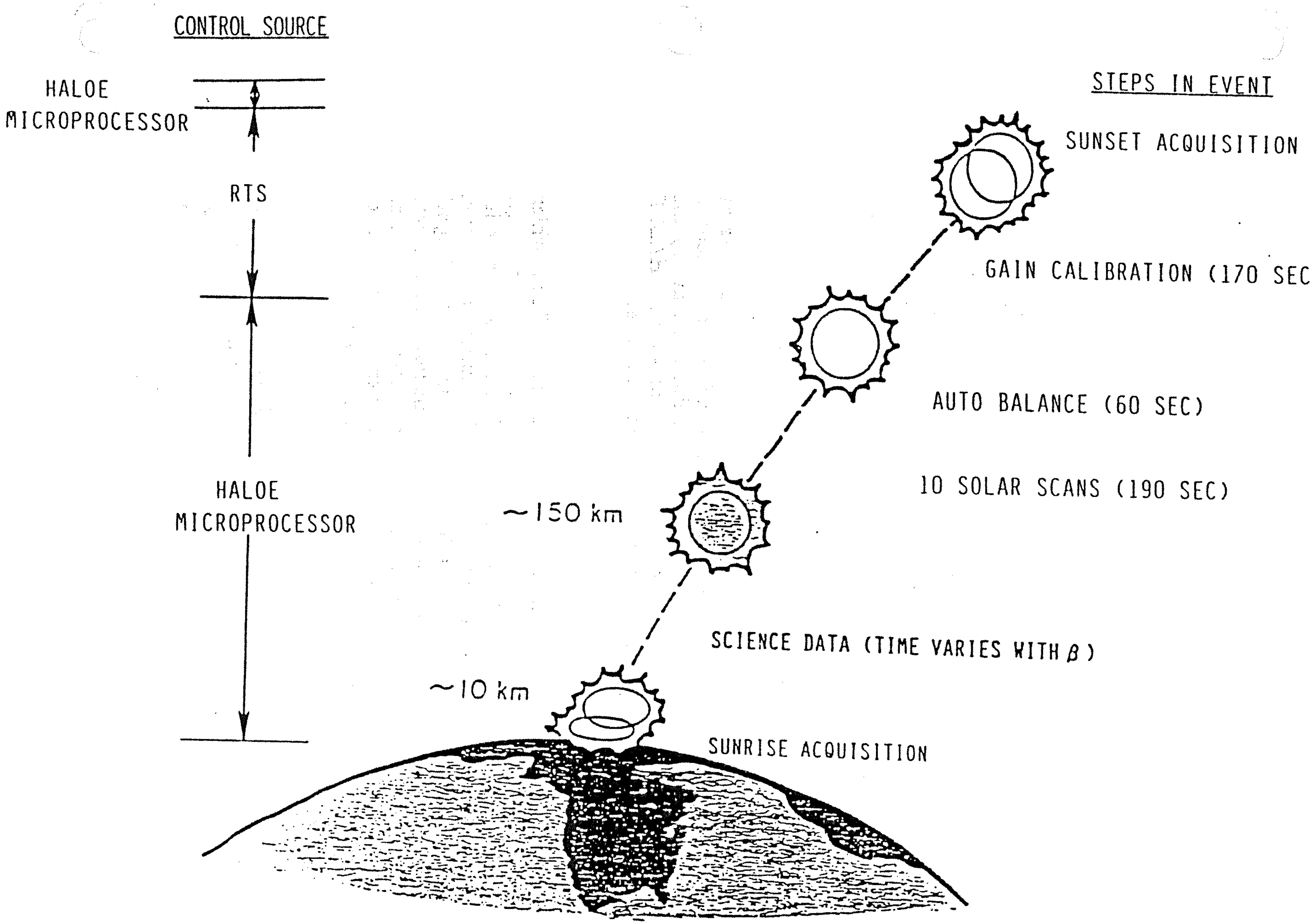


Figure 7. HALOE Sunset Event with Gain Calibration Sequence

4.2.3 *Solar Track (Drift) Sequence*

This sequence consists of two steps entirely under the control of the HALOE microprocessor. After solar acquisition, the auto balance step (Section 4.2.1.1) is completed and then the HALOE instrument tracks the Sun without interruption until the end of the event. As noted in Section 4.1.5, the sunset solar track sequence should be followed by a sunrise solar track sequence. The rationale for the sequence and its frequency are given in Section 4.1.5.

4.3 Stow

Between events, the HALOE instrument will be placed in a stow position for purposes of thermal control and contamination protection. In general, the stow position will face the HALOE telescope opening in the antivelocity direction. The capability exists, however, to change this position whenever it is deemed necessary. Furthermore, the capability exists to change either the "day" (between sunrise and sunset) stow or "night" (between sunset and sunrise) stow position independently. As noted in Sections 2 and 3, each sunrise and sunset sequence ends with commands to slew the instrument to the appropriate stow position.

5.0 NEAR-GRAZE AND GRAZE EVENTS

When the ß angle exceeds 65 degrees, UARS will experience a "grazing event" during which the Sun will be in view of the spacecraft for an extended period of time, which may last for up to 8 days. During this time, and during the several orbits immediately preceding and following the graze events, HALOE operations will be modified from the routine operations described above.

5.1 Near-Graze Events

As the graze event becomes closer in time, the amount of time which UARS spends in the Earth's shadow will diminish for each succeeding orbit. At some point, the shadow time will be insufficient to permit HALOE to slew to its normal "night" stow position after a sunset and return to the sunrise acquisition position. HALOE operations will compensate for this by changing the "night" stow position to the predicted sunrise position so that there is no lost time to create the possibility of lost events. The sunrise and sunset event sequences will be those described in sections 2, 3, and 4. At the end of the graze event the amount of shadow time will gradually increase until routine operations can be resumed.

5.2 Graze Events

Once UARS enters a graze event, HALOE operations will change to some extent. Sunset acquisition will be planned to occur at a solar elevation angle of 0 degrees. Either of the sunset sequences described in Section 4.2 will be performed and then the Sun will be tracked for science data down to its lowest elevation angle. At the time corresponding to this angle, a sunrise command will be issued from the OBC. HALOE will then track the Sun to an elevation angle of be issued from the OBC. HALOE will then track the Sun to an elevation angle of approximately -16 degrees and then initiate one of the four health and calibration sequences described in Section 4.1. The sequence will end, as usual, with HALOE in the day stow position.

HALOE will probably not attempt to obtain science data during any orbit for which the solar elevation angle does not go below -16 degrees (TBR). This means that HALOE may remain in stow for several days during the central portion of a lengthy graze event.

6.0 MODIFIED SEQUENCES

Through the use of memory updates and modified RTS procedures, it will be possible to modify the sequences described above or to create new sequences to meet specific situations which arise during the UARS mission. Some examples of the many modifications which are possible, are the following:

- Manual electronic balance of the HALOE instrument
- Deletion of selected items (e.g. calibration wheel rotation) from the activities under HALOE microprocessor control
- Change the time increment between steps in an RTS
- Change the time in a given sequence at which the RTS interrupts the HALOE microprocessor

These modifications provide greatly enhanced flexibility to HALOE operations and ensure that HALOE will be able to modify the sunrise and sunset sequences to meet the requirements imposed by changing conditions during the UARS mission.

7.0 EMERGENCY OR FAILURE SITUATIONS

From the perspective of HALOE operations, emergency situations will occur if UARS declares an emergency or if selected HALOE temperatures or voltages exceed previously defined limits. If a spacecraft emergency occurs, HALOE standard procedures require that the HALOE instrument be placed in the day stow position before instrument power is turned off and survival power turned on. If a HALOE emergency occurs due to temperature limit exceedances in the telescope secondary mirror (SMIRRT) or bolometer area (TBAT) or due to an over-voltage condition in the bolometer voltage (P29V), the emergency will be detected by the onboard telemetry monitor. This monitor will automatically issue an RTS which interrupts HALOE operations and sends HALOE to stow before turning off all power to the instrument. The POCC will be alerted to the emergency during the next TDRSS contact and will notify the HALOE FOT of the situation. Finding and correcting the cause of the problem will be the responsibility of the HALOE FOT working in conjunction with the POCC. If a HALOE emergency occurs due to temperature or voltage limit exceedances at other places in the instrument, the first indication of a problem will appear in either the real-time or quick-look data. The response to this situation will depend on a coordinated approach which involves both the POCC and the HALOE FOT.

The possibility also exists that the HALOE instrument will fail to acquire the Sun for any one of several reasons. This failure could leave the HALOE instrument in a vulnerable position for an extended period of time. In order to prevent damage to the instrument from these circumstances, HALOE procedures require that every event end with an OBC issued ATC which initiates a slew to stow maneuver. If HALOE is at or on its way to stow this command is redundant. If HALOE is still waiting for solar acquisition the "back-up" stow command will instruct the instrument to go to stow and wait for further instructions. The HALOE sun sensor field of view is such that for most of the β angle range four consecutive sunrise or sunset failures can be tolerated before it becomes necessary to update the HALOE memory with current values of the solar azimuth angle for succeeding events. Four consecutive failures would, however, alert the HALOE FOT of the need to find and correct the situation causing the failures. This would require coordination with the POCC to access real time and quick look data and to formulate and send express command loads to HALOE.

Appendix B

UARS Correlative Measurements Overview, Altitude Ranges, Measurement Locations, and Schedule

PRELIMINARY

TABLE 3. UARS Correlative Measurements

(a) Ground Based

	Correlative Measurement Category		
CMI	Validation	Complementary	Additional
Chanin	T, Density Profile		
Connor	O_3		
de Zafra	O_3, N_2O, ClO	HO_2	
Godin	O_3, Aerosols		
McDermid	O_3, T(?)		
McGee	O_3, T		
Murcray	All UARS Chemical Constituents except ClO	All UARS Chemical Constituents	CCl_4
Olivero	H_2O		
Roscoe (SOAZ Network)	O_3, NO_2		
Shwartz	H_2O		
Solomon	O_3, NO_2	NO_3, BrO	OClO
Toon	T, P, H_2O*, H_2O_2, O_3, CH_4*, CO_2*, N_2O*, CF_2Cl_2*, $CFCl_3$*, NO, NO_2, N_2O_5, HNO_3, $ClNO_3$, HCl, HF	HO_2NO_2	CO*, OCS*, HCN*, CCl_4, CF_4, COF_2, CHF_2Cl, CH_3Cl, C_2H_2*, C_2H_6*, HDO*, CH_2O
Visconti	T		

*See Appendix A for limitations.

(b) Balloon Borne and Rocket and/or Sonde

	Correlative Measurement Category		
CMI	Validation	Complementary	Additional
Almedieu (Balloon)	T, P, O_3, NO, NO_2, HNO_3, H_2O, Aerosols		Albedo, NOy (total)
Margitan (Balloon)	O_3		
Moreau (Balloon)	O_3		

PRELIMINARY

Murcray (Balloon)	NO, NO_2, N_2O_5, CH_4, H_2O, O_3, HNO_3, $CFCl_3$, CF_2CL_2, $ClONO_2$, HCL		CCl_4, CO
Murcray (Sonde)	HNO_3		
Naudet (Balloon)	O_3, NO_2 Aerosol, P	NO_3	Optical Depth
Nolt (Balloon)	$^{48}O_3$, $^{50}O_3$, H_2O_2, H_2O, CHl, HF, ClO, N_2O_5, NO_2, HNO_3, N_2O	HO_2, HOCl, OH	HDO, HBr, HCN
Oltmans (Balloon)	H_2O		
Pickett (Balloon)	OH		
Stachnik (Balloon)			
200 GHz	O_3, ClO		
600 GHz	O_3, ClO, HCl, N_2O, HNO_3	HO_2	
Toon (Balloon)	T, P, H_2O, H_2O_2, O_3, CH_4, CO_2, N_2O, CF_2Cl_2, $CFCl_3$, NO, NO_2, N_2O_5, HNO_3, $ClNO_3$, HCl, HF	HO_2NO_2, HOCl	CO, OCS, HCN, CCl_4, CF_4, COF_2, CHF_2Cl, CH_3Cl, C_2H_2, C_2H_6, HDO, CH_3D
Traub (Balloon)	T, P, H_2O, N_2O O_3, OH H_2O, NO_2, N_2O_5, HNO_3 HCl, HF, CO_2	$O(^3P)$, HO_2, HOCl	CCl_4, $ClNO_3$
Webster	$^{48}O_3$, $^{50}O_3$, H_2O_2, NO_2, HNO_3, CO_2, N_2O_5 (inferred), H_2O, NO, N_2O, CH_4, ClO, HCl	NO_3, HO_2, OH, HOCl	C_2H_2, HCN, OClO, CO, HDO
Ziph (Rocket)	CO_2, $CFCl_3$, N_2O, CH_4, CF_2Cl_2		N_2, O_2, Ar, Kr, H_2, CCl_3, $CHClF_2$, CH_3Cl, CCl_2, CF_4, $^{12}C/^{13}C$, $^{18}O/^{16}O$, $^{17}O/^{18}O$, $^{36}Ar/^{40}Ar$

(c) Dynamics

CMI	Correlative Measurement Category: Validation	Complementary	Additional
Chanin	Horizontal Wind Vectors		
Espy	Airglow Imaging of OH Waves Oxygen Twilight and Nightglow Emissions Tropospheric, Stratospheric, Mesospheric Winds		
Fritts	Horizontal Winds		

PRELIMINARY

[redacted]	[redacted]		
Killeen	Airglow Imaging of OH Waves Upper Mesospheric and lower Thermospheric Winds Temperature, Density		
Smith	Vertical Wind Horizontal Wind	Mesosphere	
Swenson	Vertical Wind Horizontal Wind OH Waves	Upper Mesosphere and Lower Thermosphere	Gravity Wave Imaging
Thuillier	Vertical Wind Horizontal Wind OH Waves and Intensity		
Wickwar	Temperature Density Vertical Wind Horizontal Wind Airglow Temperature and Intensity	Troposphere, Stratosphere and Mesosphere	

Schedule and Location:

Baseline schedules and locations for the correlative measurements during calendar years 1991-1993 are presented on Figure 5. The schedule assumes a launch in the fall of 1991 and is based on the correlative measurements program as defined at the conclusion of the Calverton Maryland workshop of February 1991. Updates of the schedule are expected, and changes to the schedule will be made as updates occur. The schedule will be reviewed and updated once a month as described in the DATA MANAGEMENT, UARS Correlative Measurements Planning Aid section of this plan.

Figures 5a, 5b, and 5c document the ground based, balloon and rocket or sonde, and dynamics types of measurements, respectively. A fourth type, surface shipboard, is present but it is included as a "ground based" measurement on Figure 5a.

The three types of measurements on Figure 5 are further separated into five latitudinal groupings; Norther High Latitudes (N50°Lat+), Mid-Northern Latitudes (N20°Lat to N50°Lat), Tropics (N20°Lat to S20°Lat), Mid-Southern Latitude (S20°Lat to S50°Lat), and Southern High Latitudes (S50°Lat+).

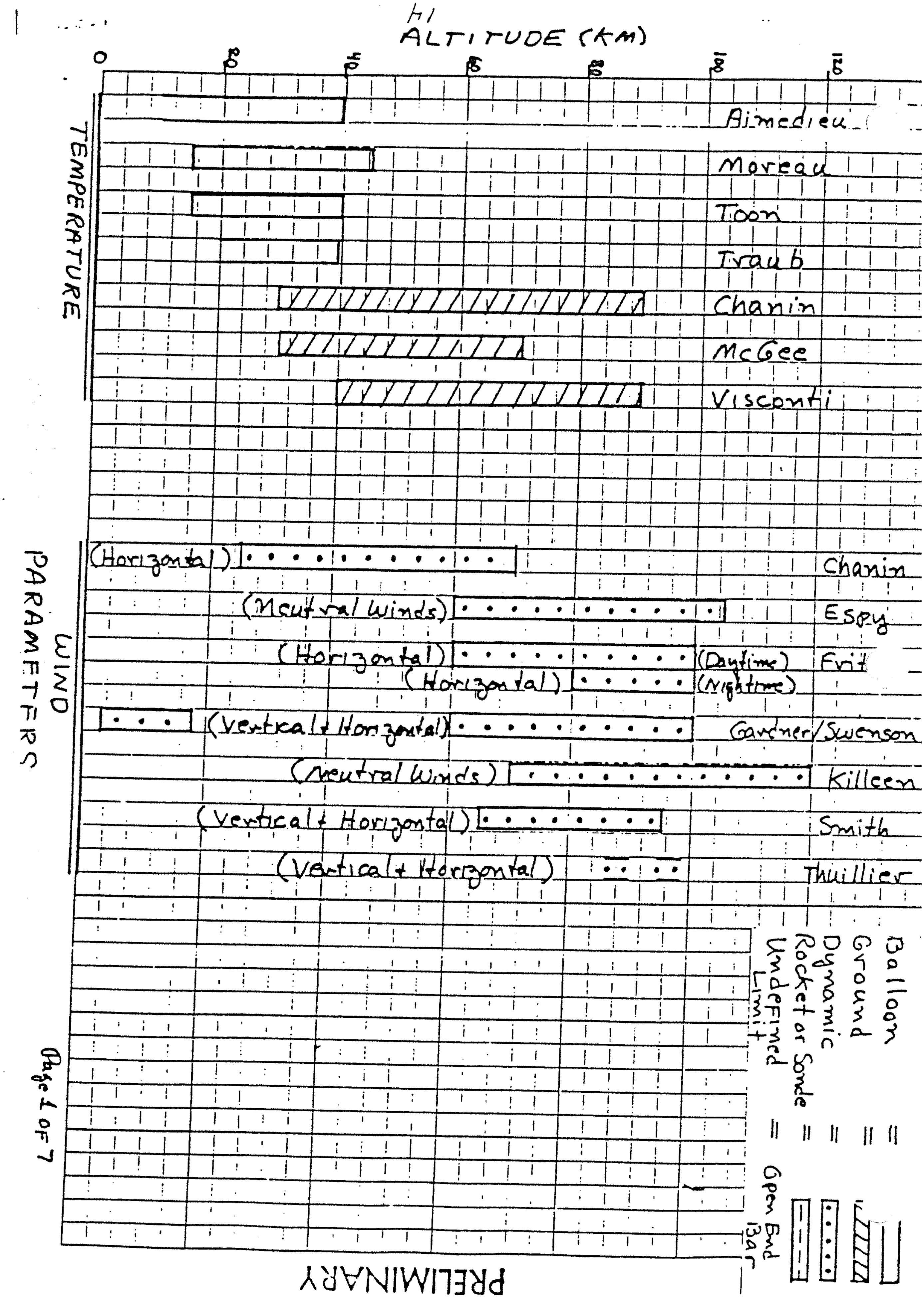
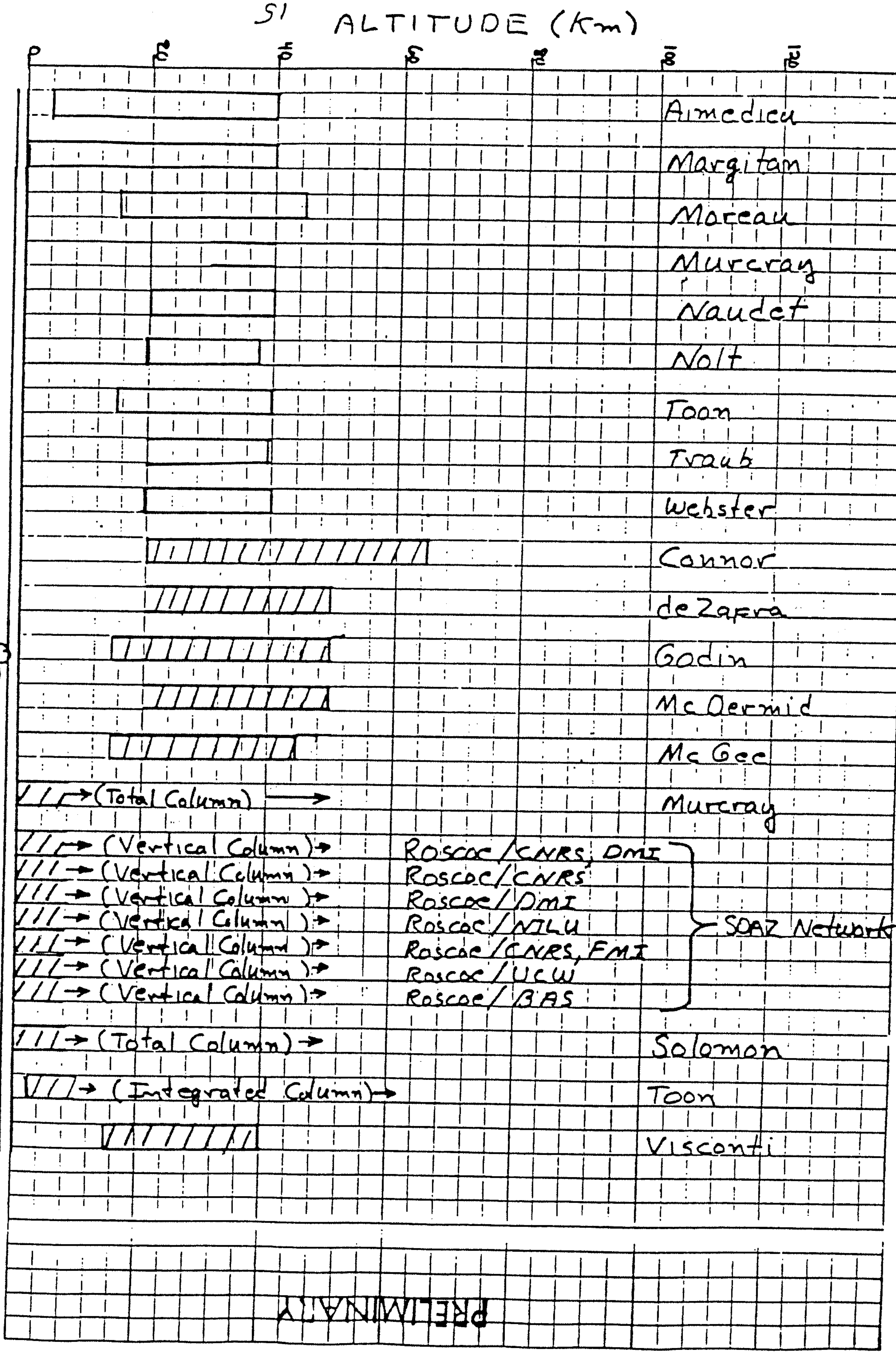


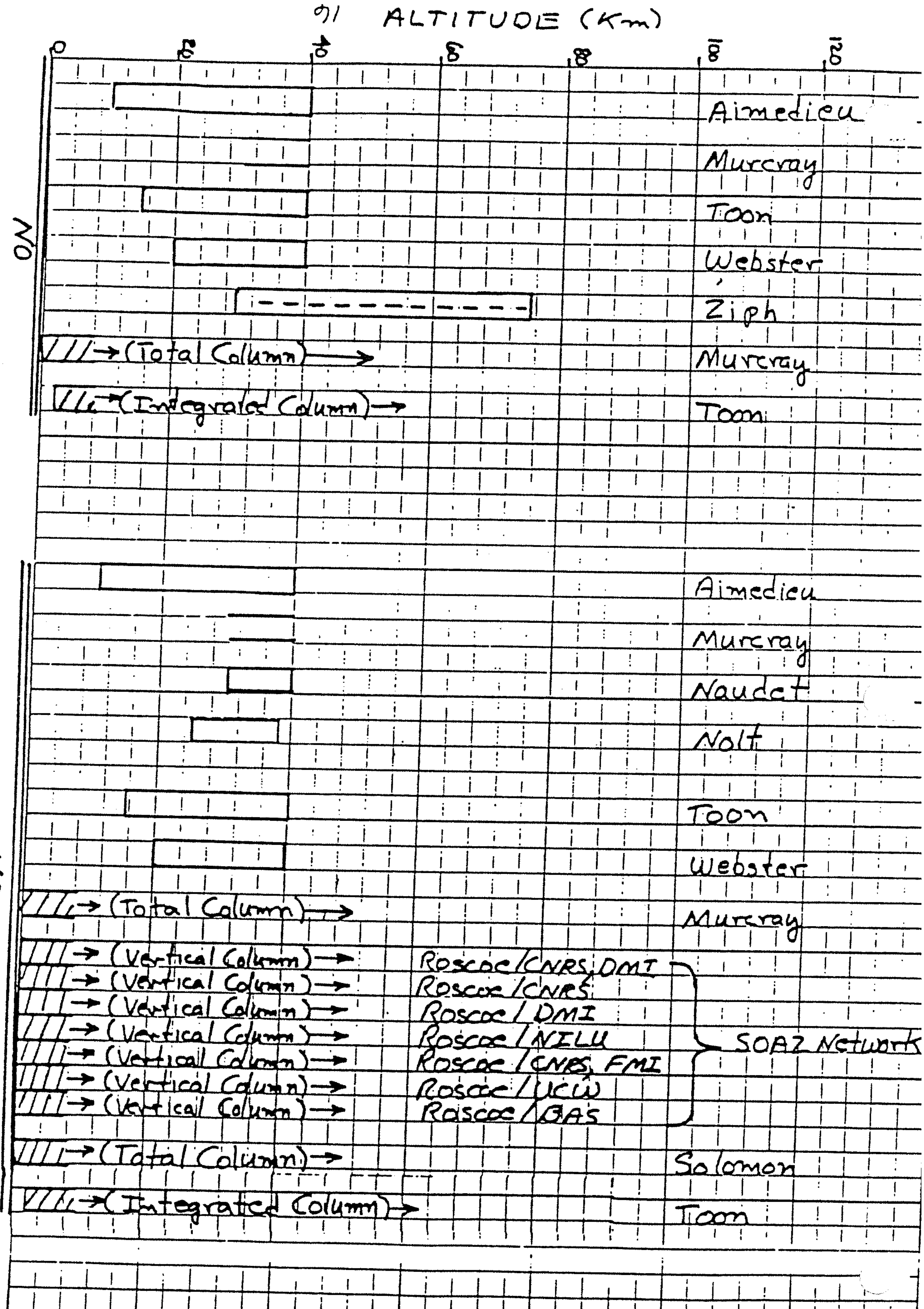
Figure 4 (b) - Altitude coverage of the atmospheric parameters measured by the



PARAMETERS
O_3

Figure 4(b)- Continued

Figure 4 (b) - Continued



PRELIMINARY

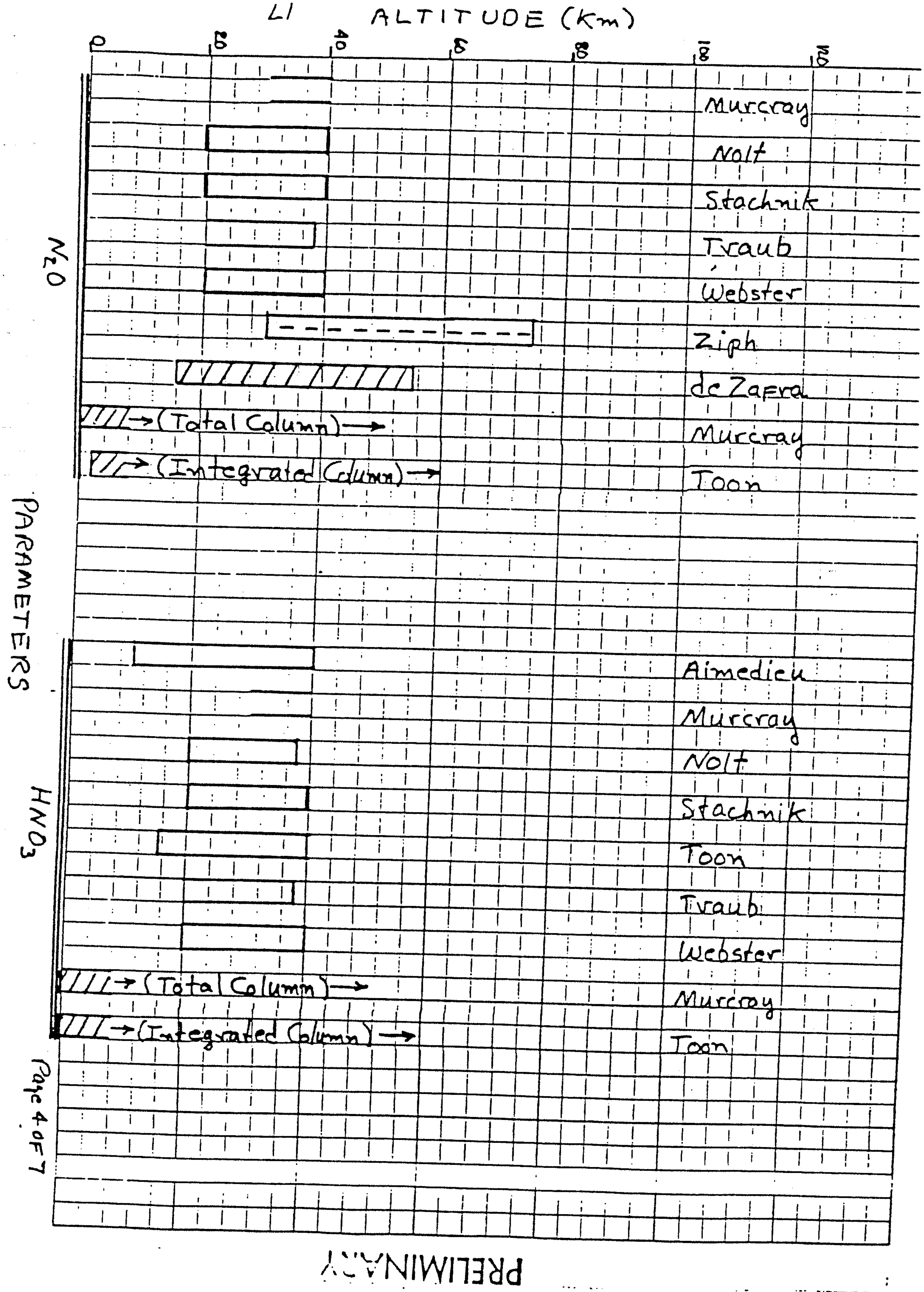
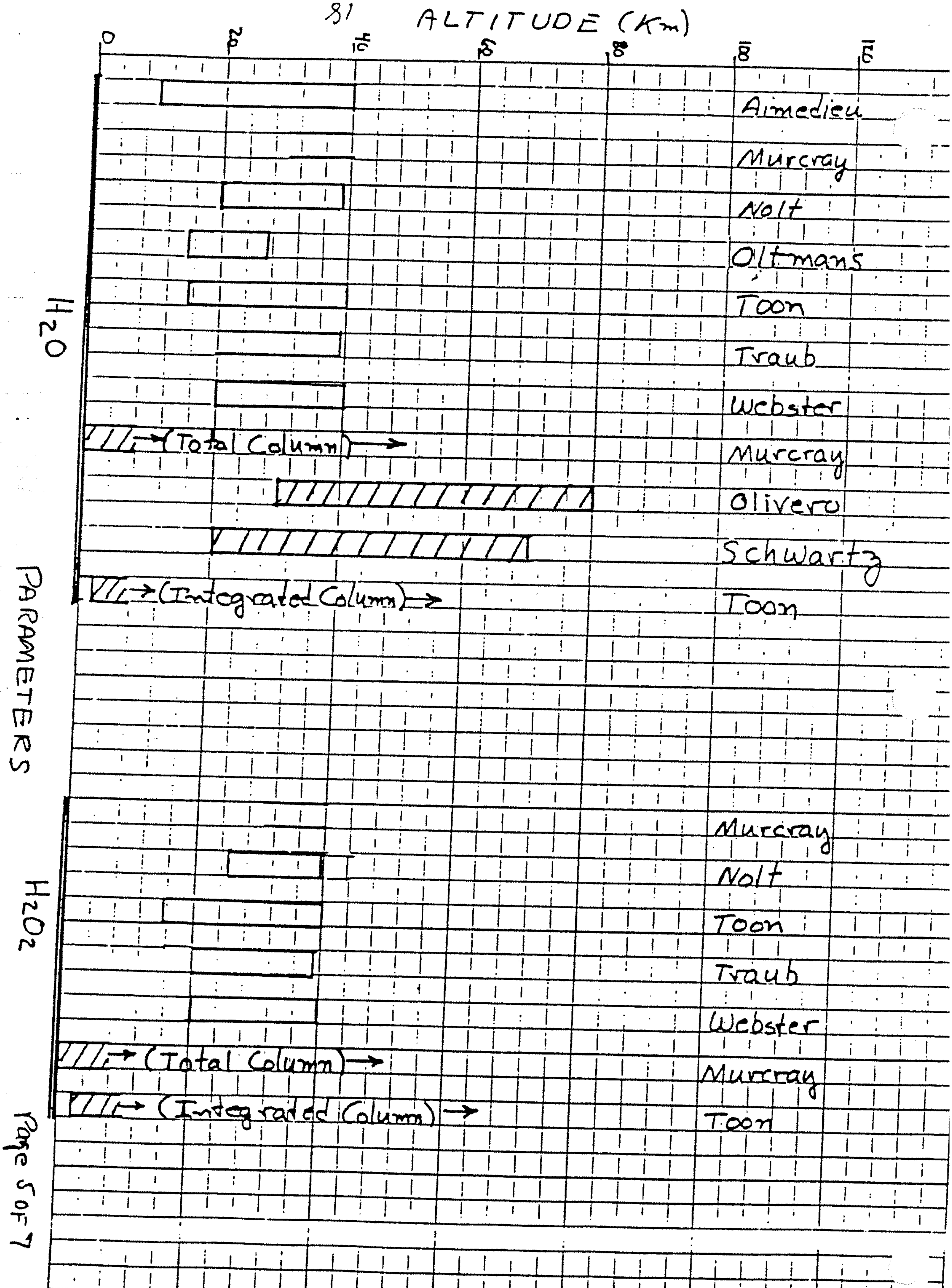


Figure 4 (d) - Continued

Figure 4 (b)- Continued



PRELIMINARY

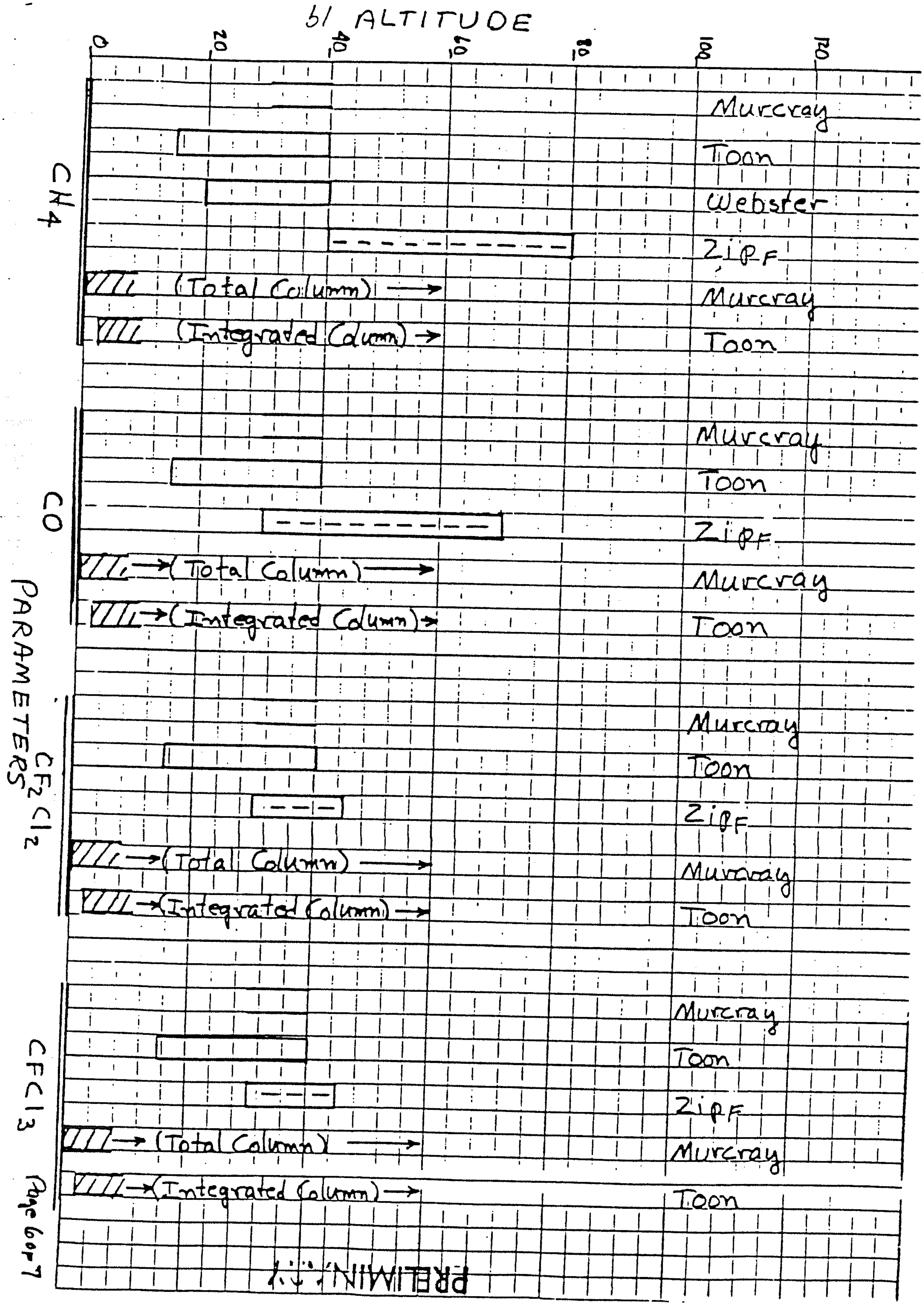
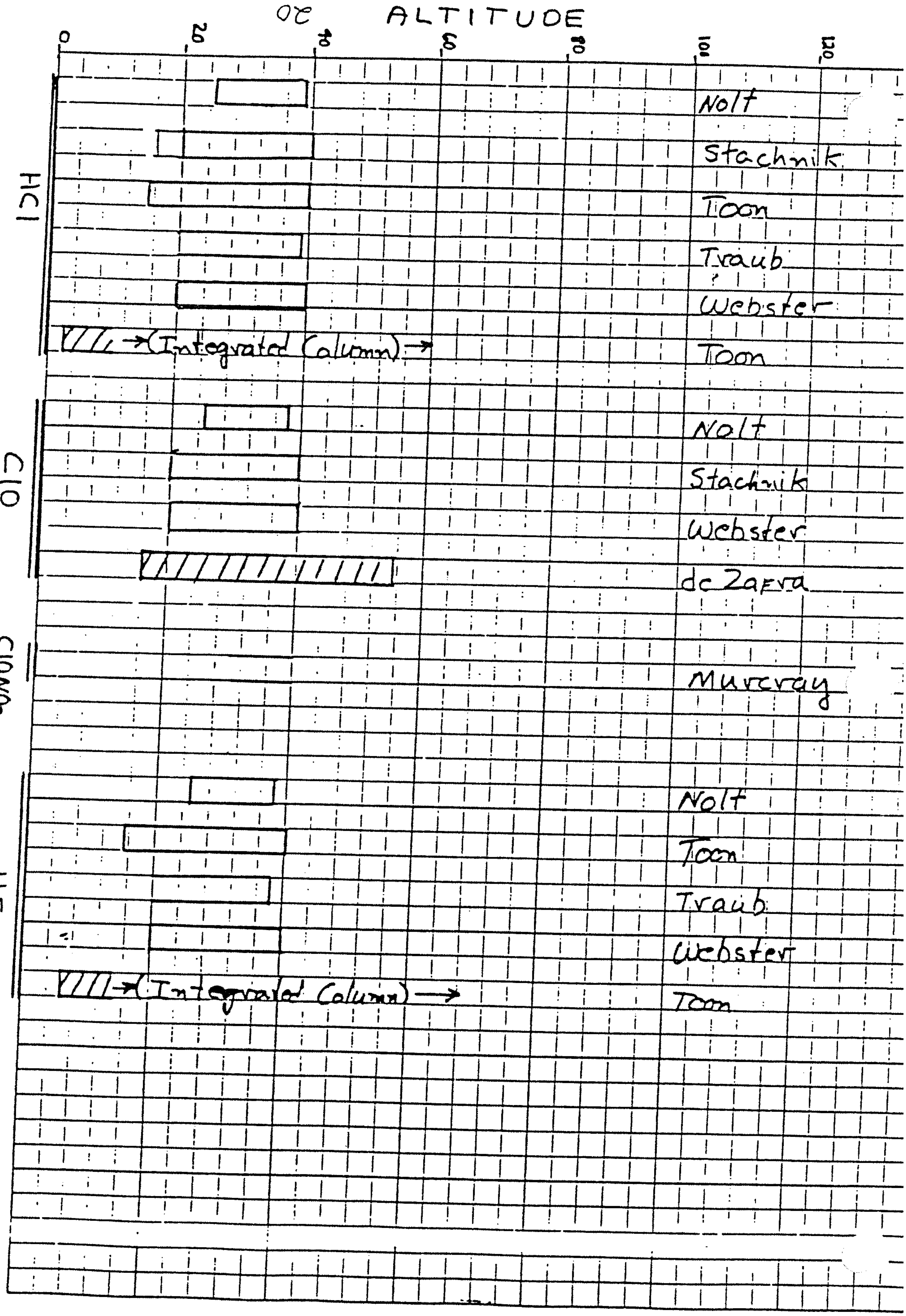


Figure 4 (b) - Continued

Figure 4 (b) - Concluded



PRELIMINARY

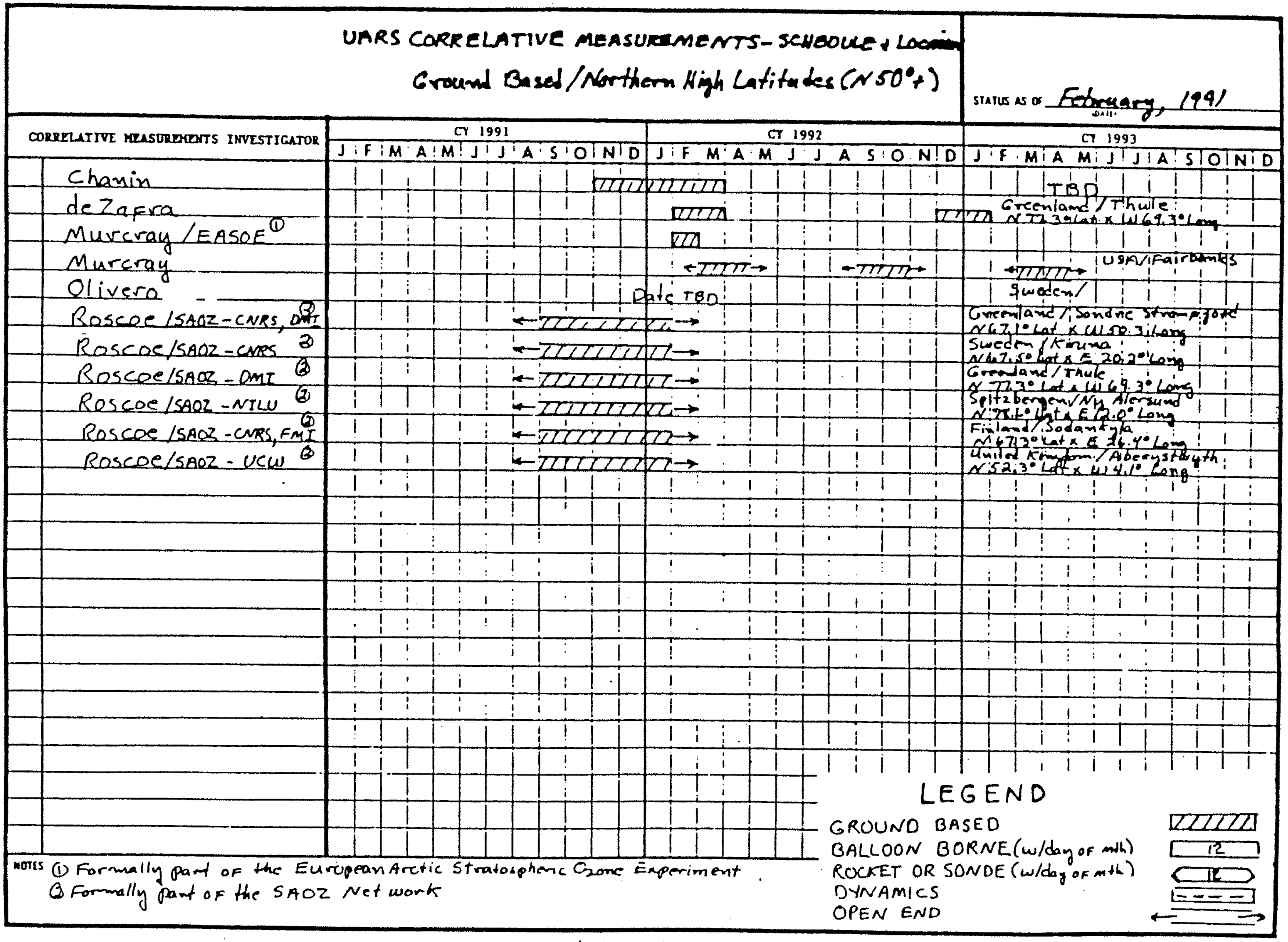


Figure 5. - Baseline schedules and locations for the correlative measurements
(a) Ground based

PRELIMINARY

UARS CORRELATIVE MEASUREMENTS – SCHEDULE & LOCATION

Ground Based/Northern Mid-Latitudes (N50° to N20°)

STATUS AS OF February, 1991 (DATE)

CORRELATIVE MEASUREMENTS INVESTIGATOR	CY 1991 – CY 1992	CY 1993
Bevilacqua	Ground based, Nov 1991 – Mar 1992	USA/Table Mountain Observatory, CA N34°22.9' Lat x W117°40.8' Long
Connor	Ground based, Nov 1991 – Mar 1992	USA/Table Mountain Observatory, CA N34°22.9' Lat x W117°40.8' Long
Connor	Ground based, Jun – Jul 1992	France/OHP N44° Lat x E 6° Long
Chanin	Ground based, Apr – Jun 1992	France/OHP N44° Lat x E 6° Long
Godin	Ground based, Aug – Dec 1991, open end	France/OHP N44° Lat x E 6° Long
McDermid	Ground based, Aug – Nov 1991, open end	USA/Table Mountain Obs. CA N34°22.9' Lat x W117°40.8' Long
McGee	Ground based, Jan – Feb 1992	USA/Table Mountain Obs. CA N34°22.9' Lat x W117°40.8' Long
McGee	Ground based, Jun – Jul 1992	France/OHP N44° Lat x E 6° Long
Meriwether	Ground based, Aug – Dec 1991, open end	USA/Hanscom AFB, MA N42°27' Lat x W71°16' Long
Olivero	Ground based, Jul – Dec 1991, open end	USA/University Park, PA N41° Lat x W78° Long
Olivero	Ground based, Feb – Mar 1992	USA/Table Mountain Obs. CA N34°22.9' Lat x W117°40.8' Long
Roscoe	Ground based, Apr – Jul 1992	USA/Table Mountain Obs. CA N34°22.9' Lat x W117°40.8' Long
Roscoe	Ground based, Aug 1992	France/Verrieres N48°42' Lat x E 2°12' Long
Roscoe/SAOZ-CNRS ①	Ground based, Jul – Dec 1991, open end	France/Verrieres N48°42' Lat x E 2°12' Long
Roscoe/SAOZ-CNRS ①	Ground based, Jul – Dec 1991, open end	Switzerland/Jungfraujoch N46.5° Lat x E 7.4° Long
Roscoe/SAOZ-U.K. Wales ①	Ground based, Jul – Dec 1991, open end	United Kingdom/Univ. Cambridge, Wales N52.3° Lat x W4.1° Long
Roscoe/SAOZ-CNRS ①	Ground based, Jul – Dec 1991, open end	France/OHP N44° Lat x E 6° Long
Solomon, Mount	Ground based, Jul – Dec 1991, open end	USA/Fritz Peak Obs. CO N39.9° Lat x W105.5° Long
Toon	Ground based, Jul – Dec 1991, open end ②	USA/Table Mountain Obs. CA N34°22.9' Lat x W117°40.8' Long
Viscomti (Aerosols & Temp.)	Ground based, Jul – Dec 1991, open end	Italy/Frascati
Visconti (Aerosols & O3 Lidar)	Ground based, Jul – Dec 1991, open end	Italy/L'Aquila

NOTES. ① Formally part of the SAOZ Network
② Continuous operation at TWO interrupted by balloon flights

LEGEND

- GROUND BASED
- BALLOON BORNE (w/day of mth)
- ROCKET OR SONDE (w/day of mth)
- DYNAMICS
- OPEN END

(a) Ground based - Continued

PRELIMINARY

UARS CORRELATIVE MEASUREMENTS – SCHEDULE & LOCATION

Ground Based/Tropics (N 20° to S 20°)

STATUS AS OF February, 1991 (DATE)

CORRELATIVE MEASUREMENTS INVESTIGATOR	CY 1991 (J F M A M J J A S O N D)	CY 1992 (J F M A M J J A S O N D)	CY 1993 (J F M A M J J A S O N D)
Chanin			La Réunion Island
Connor			USA/Mauna Loa Hawaii N19.5° Lat x W155.5° Long
de Zafra			USA/Mauna Kea Hawaii N19.5° Lat
McDermid		?	USA/Mauna Loa Hawaii N19.5° Lat x W155.5° Long
Murcray		2 weeks Every 2 Months	USA/Mauna Loa Hawaii N19.5° Lat x W155.5° Long
Bevilacqua			USA/Mauna Loa Hawaii N19.5° Lat x W155.5° Long
Solomon, Mount			

NOTES

LEGEND

- GROUND BASED
- BALLOON BORNE (w/day of mth) 12
- ROCKET OR SONDE (w/day of mth) 12
- DYNAMICS
- OPEN END

PRELIMINARY

(a) Ground based – Continued

UARS CORRELATIVE MEASUREMENTS – SCHEDULE AND LOCATION

Ground Based / Southern Mid-Latitudes (S 20° to S 60°)

STATUS AS OF February, 1991 (DATE)

CORRELATIVE MEASUREMENTS INVESTIGATOR	CY 1991 (J F M A M J J A S O N D)	CY 1992 (J F M A M J J A S O N D)	CY 1993 (J F M A M J J A S O N D)
Connor			New Zealand / Lauder S 45° Lat
McGee			New Zealand / Lauder S 45° Lat
Murcray			New Zealand / Lauder S 45° Lat
Bevilacqua			New Zealand / Lauder S 45° Lat

NOTES

LEGEND

- GROUND BASED
- BALLOON BORNE (w/day of mth)
- ROCKET OR SONDE (w/day of mth)
- DYNAMICS
- OPEN END

PRELIMINARY

(a) Ground based – Continued

UARS CORRELATIVE MEASUREMENTS - SCHEDULE + LOCATION

Ground Based / Southern High Latitudes (S 50°+)

STATUS AS OF February, 1991

CORRELATIVE MEASUREMENTS INVESTIGATOR	CY 1991 (J F M A M J J A S O N D)	CY 1992 (J F M A M J J A S O N D)	CY 1993 (J F M A M J J A S O N D)
deZafra		(← Either/Or →)	Antarctica / McMurdo S 78° Lat
Godin / SAOZ-CNRS ①			Antarctica / Dumont d'Urville: S 67° Lat × E 140° Long
Murcray			Antarctica / McMurdo S 78° Lat
Roscoe / SAOZ-BAS ①			Antarctica / Faraday S (65) 3° Lat × (W) 64.3° Long
Bevilacqua		(← Either/Or →)	Antarctica / McMurdo S 78° Lat
Solomon, Mount			Antarctica / Mc Murdo S 78° Lat

NOTES ① Formally part of the SAOZ Network

LEGEND
- GROUND BASED
- BALLOON BORNE (w/day of mth)
- ROCKET OR SONDE (w/day of mth)
- DYNAMICS
- OPEN END

PRELIMIN...

(a) Ground based - Continued

UARS CORRELATIVE MEASUREMENTS - SCHEDULE & LOCATION

Ground Based / Surface Shipboard

STATUS AS OF February, 1991
(DATE)

CORRELATIVE MEASUREMENTS INVESTIGATOR	CY 1991 (J F M A M J J A S O N D)	CY 1992 (J F M A M J J A S O N D)	CY 1993 (J F M A M J J A S O N D)
Roscoe/SOAZ-CNRS[1]	← 4 to 5 Times/Yr →	← 4 to 6 Times/Yr →	France to Indian Ocean & Return

NOTES [1] Formally part of the SAOZ Network

LEGEND

- GROUND BASED
- BALLOON BORNE (w/day of mth) 12
- ROCKET OR SONDE (w/day of mth) 12
- DYNAMICS
- OPEN END

PRELIMINARY

(9) Ground based - Concluded

UARS CORRELATIVE MEASUREMENTS – SCHEDULE + LOCATION
Balloon and Rocket or Sonde/Northern High Latitudes (N 50°+)

STATUS AS OF February, 1991 (DATE)

CORRELATIVE MEASUREMENTS INVESTIGATOR	CY 1991 (J F M A M J J A S O N D)	CY 1992 (J F M A M J J A S O N D)	CY 1993 (J F M A M J J A S O N D)
Aimedieu	D: 5		Sweden/Kiruna: N67.5° Lat x E20.2° Long
Moreau	D: 5		
Murcray	D: 3		
Naudet	D: 3		(Same)
Oltsman		F: 11	
Zipf		O: 23	F: 16; M: 15; Sweden/Kiruna N67.5°Lat x E20.2°L

NOTES

LEGEND
- GROUND BASED
- BALLOON BORNE (w/day of mth) — 12
- ROCKET OR SONDE (w/day of mth) — 12
- DYNAMICS
- OPEN END

(b) Balloon and rocket or sonde

UARS CORRELATIVE MEASUREMENTS - SCHEDULE + LOCATION

Balloon and Rocket or Sonde / Tropics (N 20° to S 20°)

STATUS AS OF February, 1991 (DATE)

CORRELATIVE MEASUREMENTS INVESTIGATOR	CY 1991 (J F M A M J J A S O N D)	CY 1992 (J F M A M J J A S O N D)	CY 1993 (J F M A M J J A S O N D)
Oltmans		M: 15 ①; N: 15 ①	USA/Hawaii-Hilo N 20° Lat
Oltmans			F: 20 Brazil or Kenya ~S 5° Lat
Stachnik (600GHz), Ackett, Margitan (Shared Payload)			F: 20 Brazil or Kenya ~S 5° Lat
Webster			F: 21 Brazil or Kenya ~S 5° Lat
Zipf		J: rocket 1	USA/White Sands N 33° Lat

NOTES ① Also listed on Balloon and Rocket or Sonde/Northern Mid-Latitudes (N 20° to N 50°)

LEGEND

- GROUND BASED
- BALLOON BORNE (w/day of mth)
- ROCKET OR SONDE (w/day of mth)
- DYNAMICS
- OPEN END

PRELIMINARY

(b) Balloon and rocket or sonde - Continued

UARS CORRELATIVE MEASUREMENTS – SCHEDULE & LOCATION

Dynamics / Northern High Latitudes (>50°)

STATUS AS OF OCT 1993

CORRELATIVE MEASUREMENTS INVESTIGATOR	CY 1991 J F M A M J J A S O N D	CY 1992 J F M A M J J A S O N D	CY 1993 J F M A M J J A S O N D
	(Dynamics Schedule + Location TBD)		

NOTES

LEGEND

- GROUND BASED
- BALLOON BORNE (w/day of mth) 12
- ROCKET OR SONDE (w/day of mth) 12
- DYNAMICS
- OPEN END

PRELIMINARY

(C) Dynamics