WIND IMAGING INTERFEROMETER

WINDII

O_2 ALGORITHM

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add Intro.

Superscript for line.

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Preface

This document presents the algorithms to be used for the analysis of O_2 observations from WINDII. A summary of the scientific ideas on which the algorithm is based is presented in the document "The O_2 Algorithm, Conceptual Summary''. This latter document should be read by anyone wishing an overview of the algorithm. The present document provides the details of the algorithm.

For clarity of understanding, several conventions are used in this document. As in the "WINDII Algorithm Description", the subscripts h, i, j, and k refer, respectively, to the field of view, row, column, and image in the measurement under consideration. In addition, eight emissions in the 0 - 0 band of the O_2 atmospheric band system, namely the ${}^{Q}P(3)$, ${}^{P}P(3)$, ${}^{Q}P(5)$, ${}^{P}P(5)$, ${}^{Q}P(7)$, ${}^{P}P(7)$, ${}^{Q}P(9)$, and ${}^{P}P(9)$ lines, contribute to the intensity measured at any given bin. These contributions are distinguished using the superscript m. Quantities subscripted by these indices are functions of these indices.

In this algorithm, the subscripts i and j may refer to a number of different windows and bin sizes. In particular, the bin size being referred to may be individual pixels on the CCD, the binning used for quantities in the CDB or the binning used for the measurement, and the window being referred to may be the full CCD, the measurement window, or a sub-window in the measurement window. To aid the reader in identifying which quantity is being referred to, the following further conventions are followed.

1. If a quantity is calculated on a pixel by pixel basis, it is superscripted by a "p''.
2. For the filter parameter calculations a subwindow in the measurement window is used. To distinguish quantities associated with this smaller window from other quantities, they are superscripted with a "W''.

Finally, quantities which depend on the aperture are superscripted by "A''.

Part I

A1 - Telemetry Depacking

CHAPTER 1

A11 - Quality checks

As is currently being done, A11.

CHAPTER 2

A12 - Depack data

As is currently being done, A12.

CHAPTER 3

A13 - Catalog data

As is currently being done, A13. It should be noted that the O_2 data are written to special files, distinct from the files associated with the other emissions.

Part II

A2 - Data Calibration

CHAPTER 4

A21 - Remove instrumental effects

4.1 A211 - Subtract dark current

As is currently being done, A211.

4.2 A212 - Convert from counts to Rayleigh

As is currently being done, A212, except the calculation of MT_{hij} is not needed.

CHAPTER 5

A22 - Remove observatory effect

5.1 A221 - Determine altitude of the bins

The algorithm to be used here is the same as is currently being implemented, A221.

5.2 A222 - Determine instrument phase

FUNCTIONAL DESCRIPTION:

In order to determine the atmospheric motion relative to the earth the contribution to the total phase of the instrument, the mirror step, the spacecraft velocity and the earth rotation must be calculated. In this function these various contributions to the total phase are calculated. The expression for the total phase is

$$\phi^{Am}_{Thijk} = \phi^{A}_{Ghij} + \phi^{Am}_{ZW} + \phi_{OFFh} + \delta\phi_{hijk}(\lambda^{m}) + \phi^{m}_{vhij} + \phi^{m}_{whij} \qquad \textbf{(EQ 5.1)}$$

$$= \phi^{Am}_{Ihijk} + \phi^{m}_{whij} \qquad \textbf{(EQ 5.2)}$$

where

- ϕ^{Am}_{Thijk} is the total phase
- ϕ^{A}_{Ghij} is the aperture dependent phase variation across the field as measured on the ground (calculated from ϕ^{Ap}_{Bhi} are CDB parameters).

- ϕ_{ZW}^{Am} is the aperture dependent phase difference between the calibration phase and the phase of the mth emission as measured on the ground (provided in CDB).
- ϕ_{OFFh} is the aperture dependent phase difference between the calibration phase in space and the calibration phase on the ground.
- $\delta\phi_{hijk}(\lambda^{m})$ is the phase step associated with the mirror step for the mth emission. ($\delta\phi_{hijk}(\lambda^{6})$ given in CDB)
- ϕ_{vhij}^{m} is the phase associated with the spacecraft velocity and rotation of the earth for the mth emission.
- ϕ_{whij}^{m} is the phase associated with the component of the atmospheric motion (wind) relative to the earth projected along the line of sight of the hijth bin.
- ϕ_{Ihijk}^{Am} is the contribution to the total phase of all quantities except ϕ_{whij}^{m}, termed the instrument phase.

In expressing the total phase in this form, several implicit assumptions are made. First it is assumed that for each aperture a single background phase profile may be used to describe the phase variation due to the instrument across the field. Furthermore it is assumed that the form of this phase variation remains constant in time so that the phase shifts between the different O_2 emissions and the phase shift of the calibration phase between ground and space may be regarded as constants independent of position. This means that the variation across the field is associated with the ground phases variation, ϕ_{Ghij}^{A}, the spacecraft velocity phase, ϕ_{vhij} and the phase step associated with the mirror step, $\delta\phi_{hijk}(\lambda^{m})$. Of these parameters, ϕ_{Ghij}^{A} which is calculated from 5th order expansion co-efficients provided in the CDB, which is calculated from a knowledge of the wavelengths of the emissions, the associated path differences, and an expression provided in the CDB for the off-axis effect, and ϕ_{ZW}^{Am} which is provided directly in the CDB are independent of effects associated with the satellite. The remaining parameters, however require input from sources other than the CDB for their evaluation.

5.2.1 A2221 - Derive projected velocities

The algorithm for this functions is unchanged from its current implementation. However, unlike the current implementation, the data for the O_2 algorithm will need to be calculated on a pixel by pixel basis. Two strategies to accomodate this requirement are possible. These are:

1. The projected velocities can be calculated on a pixel by pixel basis at this point.
2. The attitude can be calculated for each CDB bin in the measurement window When the attitude data is required on a pixel by pixel basis, it is calculated using quadratic interpolation.

The choice of which option should be used, needs to be evaluated on the basis of the time and space constraints associated with each and how they affect the overall performance of the software. This will be decided as the software is implemented.

5.2.2 A2222 - Calculate velocity phases

The algorithm for this functions is unchanged from its current implementation except that it must be calculated for each of the 8 emissions involved in the O_2 measurement (ie all quantities are indexed with the superscript m). In addition the condition regarding whether these quantities are to be calculated on a pixel by pixel basis or on a bin by bin bases, discussed in A2221 applies here also.

5.2.3 A2223 - Calculate the phase offset relative to the ground

FUNCTIONAL DESCRIPTION:

The path difference or phase of the instrument will vary in time. This drift is monitored using the frequent phase calibration measurement. On the ground the phase variation across the CCD for this emission was measured. In this subroutine the phase difference between the ground measurement and the current measurement is determined. At the present time the night aperture is used for all frequent calibration measurements. In case this might change this algorithm is written for arbitrary aperture. The CDB is used to calculate the phase variation across each row and must be checked to ensure it has the same aperture as the associated frequent phase measurement.

INPUT:

The input parameters are:

- t - time of the current measurement (for first image).
- $\phi^{Ap}_{Bhi}(a^A_{0hi}, a^A_{1hi}, a^A_{2hi}, a^A_{3hi}, a^A_{4hi}, a^A_{5hi})$ - an array of 6 parameters for each row and FOV giving the expansion coefficients for a 5th order polynomial fit to the phase variation across each row in each field of view on the CCD. This is provided in the CDB.

  From these coefficients the phase ϕ^{Ap}_{Ghij} at the hijth pixel is given as

  $$\phi^{Ap}_{Ghij} = a^A_{0hi} + a^A_{1hi}j + a^A_{2hi}j^2 + a^A_{3hi}j^3 + a^A_{4hi}j^4 + a^A_{5hi}j^5 \qquad \text{(EQ 5.3)}$$

  where j is the pixel location in the expansion.
- C^m_L - the OPD neutral variation (from the CDB). This value depends on the filter or wavelength and is given by $C^m_L = 2\pi C^1_L\left(\frac{1}{\lambda_0} - \frac{1}{\lambda_m}\right)$ where λ_0 is the calibration wavelength, λ_m is the emission wavelength, and C^1_L is a constant given in the CDB.
- $\phi 1_{CALhij}$ - Calibration phase with the same binning as the measurement, associated with the most recent calibration prior to the measurement (from A243).
- t_1 time of the $\phi 1$ calibration measurement.

- $\phi 2_{CALhij}$ - Calibration phase with the same binning as the measurement, associated with the most recent calibration subsequent to the measurement (from A243).
- t_2 time of the $\phi 2$ calibration measurement.

OUTPUT:

The output parameters are:

- ϕ_{OFFh} is the phase difference between the calibration phase in space and the calibration phase on the ground corrected by the OPD neutral variation.

HYPOTHESIS OF APPLICABILITY:

The phase of the calibration phase relative to the ground is assumed to be independent of position on the CCD so that any variations essentially move the phase field parallel to itself. The frequent phase calibrations provide the means to monitor this offset. Because the ground measurements were made in air and the spacecraft measurements made in vacuum, an additional offset must be taken into account. This is accomplished by including the OPD neutral variation C_L^m. It is also assumed that the accuracy of the frequent phase measurement for each bin is about the same.

CRITERIA OF APPLICABILITY:

To be applied to all atmospheric Doppler measurements.

TRANSFORMATION EQUATIONS:

The following steps are to be accomplished:

1. Check the measurement type and search for the frequent calibrations which bracket the measurement. The filter groups should match giving the same window and bin size for the calibration and measurement. Okay for phase smoothing.

2. Calculate the phase of each measurement bin using the 5th order polynomial whose coefficients are given in ϕ_{Bhi}^{Ap} making sure the aperture matches the associated frequent phase calibration. This calculation is accomplished by determining the phase for each pixel in the measurement bin and determining the average for each bin. This generates the phases ϕ_{Ghij}^{A}.

$$\phi_{Ghij}^{A} = \overline{\phi_{Ghij}^{Ap}} \quad \text{average over pixels in measurement bin.} \qquad \textbf{(EQ 5.4)}$$

3. Calculate the frequent calibration phase for the measurement:

$$\phi_{Ihij} = \phi 1_{CALhij} + \frac{t - t_1}{t_2 - t_1}\left[\phi 2_{CALhij} - \phi 1_{CALhij}\right] \qquad \textbf{(EQ 5.5)}$$

These phases must be checked to ensure that there are no phase jumps in the field which might ensue from the multiply periodic nature of the phase determination.

4. Calculate the average phase offset for each window between the ground and the measurement:

$$\phi^{m}_{OFFh} = \overline{(\phi_{Ihij} - \phi^{A}_{Ghij})} + C^{m}_{L} \qquad \textbf{(EQ 5.6)}$$

Again care must be taken to ensure that phase jumps do not cause errors in the calculated phase offset.

5.2.4 A2224- Calculate the phase step

The algorithm to be used here is the same as that presently being implemented. However, similar considerations apply here as in A221, namely that a decision needs to be reached as to whether the calculation of the phase step should be accomplished on a pixel by pixel basis at this point or whether calculations on a CDB bin by CDB bin basis may be accomplished with quadratic interpolation to a pixel by pixel basis later. For the O_2 measurement the phase step is calculated solely for the ${}^{P}P(7)$ emission (m=6) at this point. The phase steps for the other emissions are calculated relative to these later in the algorithm when needed using:

$$\delta\phi^{m}_{hijk} = \delta\phi^{6}_{hijk}\frac{\lambda_6}{\lambda_m} \qquad \text{(includes off axis effect)} \qquad \textbf{(EQ 5.7)}$$

5.3 A223 - Moon angle determination

NOTE: Star corrections are not being accomplished in this section and hence are omitted.

5.3.1 A2231 - Determine the angle between the observing window and the moon

As is currently being done, A2231.

5.4 A224 - Roll effect attitude correction

As is currently being done, A224.

CHAPTER 6

A23 - Background subtraction

This chapter is not needed as the background is derived as one of the measurement parameters.

CHAPTER 7

A24 - Extract calibration parameters

7.1 A241 - Calculate phase step

As is currently being done, A241.

7.2 A242 - Calculate calibration vector

As is currently being done, A242.

7.3 A243 - Extract phase and visibility

As is currently being done, A243.

CHAPTER 8

A244 - Determine filter parameters

FUNCTIONAL DESCRIPTION:

Because it is possible that the filter parameters may drift with temperature and time (through aging) it is necessary to determine the filter parameters on orbit. There are three steps to this procedure. The first is to find suitable images from which the parameters may be derived. The criterion to be used is that the sums of images k and k+4, (k=1,..4) for an 8-point measurement, sums of images 1 and 3, 2 and 4, 5 and 7, and 6 and 8 for a double 4-point measurement or sums of images 1 and 3, and 2 and 4 for a 4-point measurement be compared to ensure the intensity variation during a measurement is minimal. When a set of images satisfying this criteria are found the filter parameters associated with each image are determined. The filter parameters to be used for the data analysis are then found by interpolation (at the present time presumed to be quadratic).

INPUT:

The input parameters are listed below in the subsequent subsections.

OUTPUT:

The output parameters are:

- $C_r^{\lambda_0 A}$ - the coefficients of the quadradic expression giving the filter parameter λ_0 as a function of universal time (r=1,,3). The coefficients are a function of aperture.
- $C_r^{\mu_e A}$ - the coefficients of the quadradic expression giving the filter parameter μ_e as a function of universal time (r=1,,3). The coefficients are a function of aperture.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the filter function is described by the Lissberger formula

$$\tau(\lambda, \theta) = \frac{\tau_{max}(\theta)}{1 + \left| \left[\frac{2(\lambda - \lambda_0)}{(\Delta\lambda)_0} + \frac{\lambda_0}{(\Delta\lambda)_0} \frac{\theta^2}{\mu_e^2} \right] \right|^{fexp}} \qquad \textbf{(EQ 8.1)}$$

Here λ_0 is the wavelength at peak transmittance at normal incidence through the filter, is an effective refractive index characterizing the dependence of transmittance with angle, $(\Delta\lambda)_0$ is the spectral half-width of the filter at normal incidence, *fexp* is an exponent controlling the filter shape, is the angle of incidence at the filter for the ray passing to a particular point on the CCD, λ is the wavelength for which the transmittance is being calculated where τ_{max} is the transmissivity as a function of the angle θ.

CRITERIA OF APPLICABILITY:

This function is to be accomplished for a set of O_2 measurements in the day which meet specific stability criteria to be set forth below.

TRANSFORMATION EQUATIONS:

The structure of this algorithm is as follows:

1. For the full day

(a) Perform A2442, starting at the first measurement until a suitable measurement is found.

(b) Perform A2443 on the suitable measurement to determine associated filter parameters.

(c) Increment the universal time by ΔT (from the CDB).

(d) Continue the cycle (a to c) starting with the next measurement after the new universal time.

2. With the filter parameters estimates from step 1, calculate a quadratic fit to the day and night values to retrieve $C_r^{\lambda_0 A}$ and $C_r^{\mu_e A}$.

8.1 A2441 - Calculation of the angles through the filter

FUNCTIONAL DESCRIPTION:

The angle of the ray passing through the filter, incident on a given pixel on the CCD, is calculated. This subroutine is only calculated once for each day of O2 observations.

INPUT:

The input parameters are:

- NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.
- NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.
- *FC* - Row of filter centre in pixels (from CDB, reference to 256 pixels).

- FC_c - Column of filter centre in pixels (from CDB). Column 0 is at the centre of the CCD and positive is to the right of the centre of the CCD.
- DP - angular size of a pixel in radians (from CDB).
- MF - magnification factor between the angular FOV of WINDII and the angular field at the filter (from CDB).

OUTPUT:

The output parameters are:

- θ^{Fp}_{hij} - the filter angles for each pixel on the CCD.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the angular field at the filter is a linear function of filter position on the CCD.

CRITERIA OF APPLICABILITY:

This is assumed to be generally valid for all O_2 measurements.

TRANSFORMATION EQUATIONS:

For all pixels in field of view 1,

$$\theta^{Fp}_{1ij} = \sqrt{(i - 0.5 - FC_i)^2 + (j - 0.5 + FC_j)^2} \bullet DP \bullet MF \tag{EQ 8.2}$$

For all pixels in field of view 2,

$$\theta^{Fp}_{2ij} = \sqrt{(i - 0.5 - FC_i)^2 + (NH_{fov} - j - 0.5 + FC_j)^2} \bullet DP \bullet MF \tag{EQ 8.3}$$

8.2 A2442 - Determine measurement suitability

FUNCTIONAL DESCRIPTION:

In order to determine the filter parameters it is important that each field of view have the same aperture and the intensity variation for the images being used is small. The purpose of this routine is to screen each measurement to ensure these conditions are met, before trying to use it. A subwindow containing intensity data near the peak of the emission is used (the row of maximum intensity, the $\delta R+$ rows above and the $\delta R-$ rows below it). For each orbit at least two night measurements and two day measurements are needed, measurements being $> \Delta T$ minutes apart.

INPUT:

The input parameters are:

- UT_1 - the universal time of the measurement for the first image in the measurement.
- $I_{R_{hijk}}$ - corrected intensity data from A22.
- N_i - the number of measurements bins in the vertical in the window.

- N_j - number of measurement bins in the horizontal in the window.
- N_k - number of phase steps in the measurement.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.
- NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.
- NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.
- $\delta R+$ - the nominal number of rows below the row of peak intensity to be considered for the filter parameter determination (from CDB).
- $\delta R-$ - the nominal number of rows above the row of peak intensity to be considered for the filter parameter determination (from CDB).
- $Flags_{hijk}$ - flags giving the good and bad bins in the window.
- MD - an average dark count in R/sec/(1 by 5 bin).
- t_k - the exposure time for a measurement image.
- ΔT - the time interval needed between measurements to ensure a suitable sampling of the filter parameters during the day is obtained. (from CDB).
- P_{BB} - a parameter giving the proportion of the reduced window in each field of view which may be contaminated by bad bins before the measurement is rejected (from CDB).
- QL - parameter (from CDB) determining whether the observed intensity variation in the image is acceptable or not.

OUTPUT:

The outputs are:

- $\overline{I_{hij}^{TW}}$ - the mean intensity image for the subwindow in the measurement to be used to determine the filter parameters.
- NM_h - index giving the row of maximum intensity.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the selection of suitable images for filter parameter determination can be based on a consideration of the aperture in each field of view, the position of the row of peak intensity in the measurement window, bad bin flags and an examination of the intensity variation during a measurement. An additional constraint is that at least two measurements each for the day and night apertures should be analysed each orbit with the measurements for each aperture for each orbit being $> \Delta T$ minutes apart.

CRITERIA OF APPLICABILITY:

To be used for all O_2 measurements considered for filter parameter determination.

TRANSFORMATION EQUATIONS:

This routine proceeds as follows:

1. Check to ensure both fields of view have the same aperture.

2. Determine a reduced window termed the "FP window" in the following, for the determination of the filter parameters using A24421. If the row of peak intensity is less than three rows from the top or bottom of the field of view the measurement is rejected and not considered for filter parameter determination. Otherwise the window consists of the row of peak intensity, $\delta R-$ rows above it and $\delta R+$ rows below it or if the measurement window is smaller than the window defined by these parameters the window to be used will consist of the largest possible window in the measurement window within the region $\delta R-$ rows above and $\delta R+$ rows below the row of peak intensity. All quantities referenced to this window are superscripted by a "W".

3. Ensure the reduced window in each field of view is not contaminated by too many bad bins. The criteria for this is set using P_{BB}, a parameter in the CDB. If, for either field of view, the proportion of bad bins to the total number of bins in the reduced window in each field of view in the image is greater than P_{BB} the measurement is rejected. **NOTE:** For the purposes of this test, bin ij is a bad bin if a bad bin flag occurs in any of the k images involving this bin.

4. Check the intensity variation in the reduced window excluding any bad bins (defined as in the previous item) from consideration, using A24422. If the intensity variation is less than a prescribed amount, given by QL the measurement is considered suitable for filter parameter estimation and data, $\overline{I}^{TW}_{hij}$, giving the mean intensity image for the filter parameter determination, and NM_h, the index giving the row of maximum intensity are passed to A2443.

8.2.1 A24421 - Determine Row of peak intensity in Measurement

FUNCTIONAL DESCRIPTION:

The row of peak intensity in each field of view is determined by summing over the columns in images k_1^8 and k_2^8 for an 8-point measurement or the first columns in images k_1^4 and k_2^4 for the double four-point or four-point measurement, to produce a single line of sight profile of intensity. This profile is then examined to find the row index of the peak intensity. If a bad bin flag appears in the hijth bin in either image it is not included in the calculation of the line of sight profile.

INPUT:

The input parameters are:

- $I_{R_{hijk}}$ - Corrected intensity data from A22.
- $Flags_{hijk}$ - Flags giving the good and bad bins in the window
- N_k - Number of phase steps in the measurement.
- k_1^8 and k_2^8 - Indices denoting the images to be used for eight point measurements (from CDB).
- k_1^4 and k_2^4 - Indices denoting the images to be used for double four-point or four-point measurements (from CDB).

OUTPUT:

The output is:

- NM_h - the row of peak intensity.

HYPOTHESIS OF APPLICABILITY:

The sum of images k_1^8 and k_2^8 in an eight-point measurement or imagess k_1^4 and k_2^4 in a double four-point or four-point measurement provide a useful estimation of the line of sight intensity for the image.

CRITERIA OF APPLICABILITY:

To be applied to all images being considered for filter parameter estimation.

TRANSFORMATION EQUATIONS:

For eight point measurements:

For each window calculate

$$IM_{hij} = Flags_{hijk_1^8} Flags_{hijk_2^8} \left(I_{R_{hijk_1^8}} + I_{R_{hijk_2^8}} \right) \qquad \textbf{(EQ 8.4)}$$

$$NB_{hi} = \sum_j Flags_{hijk_1^8} Flags_{hijk_2^8} \qquad \textbf{(EQ 8.5)}$$

$$IM_{hi}^* = \frac{1}{NB_{hi}} \sum_j IM_{hij} \qquad \textbf{(EQ 8.6)}$$

FOR double four-point or four-point measurements

For each window calculate

$$IM_{hij} = Flags_{hijk_1^4} Flags_{hijk_2^4} \left(I_{R_{hijk_1^4}} + I_{R_{hijk_2^4}} \right) \qquad \textbf{(EQ 8.7)}$$

$$NB_{hi} = \sum_j Flags_{hijk_1^4} Flags_{hijk_2^4} \qquad \textbf{(EQ 8.8)}$$

$$IM_{hi}^* = \frac{1}{NB_{hi}} \sum_j IM_{hij} \qquad \textbf{(EQ 8.9)}$$

Search IM_{hi}^* to find $NM_h \equiv$ The row of maximum intensity for each field of view.

8.2.2 A24422 - Check measurement for intensity variation

FUNCTIONAL DESCRIPTION:

The intensity variation for a measurement may be determined by considering the intensity variation of the series of image sums in the FP window,

$$(I_{R_{hijl}} + I_{R_{hij(l+4)}}), l = 1, \ldots, 4 \qquad \text{(EQ 8.10)}$$

for the eight-point measurement,

$$\left(I_{R_{hijl_1}} + I_{R_{hijl_2}}\right), (l_1, l_2) \in \{ (1, 3), (2, 4), (5, 7), (6, 8) \} \qquad \text{(EQ 8.11)}$$

for the double four-point measurement, and

$$\left(I_{R_{hijl_1}} + I_{R_{hijl_2}}\right), (l_1, l_2) \in \{ (1, 3), (2, 4) \} \qquad \text{(EQ 8.12)}$$

for the four-point measurement. If the variation is less than a predetermined amount (given by QL) the measurement is accepted for filter parameter determination.

INPUT:

The input parameters are:

- NM_h - the row of peak intensity (from A24421).
- $I_{R_{hijk}}$ - Corrected intensity data from A22.
- $Flags_{hijk}$ - Flags giving the good and bad bins in the window
- N_i - number of measurement bins in the vertical in the window.
- N_j - number of measurement bins in the horizontal in the window.
- N_k - number of steps in the measurement.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.
- $\delta R+$ - the number of rows below the row of peak intensity to be considered for the filter parameter determination (from CDB).
- $\delta R-$ - the number of rows above the row of peak intensity to be considered for the filter parameter determination (from CDB).
- MD - an average dark count in R/sec/(1 by 5 bin), from CDB.
- t_k - the exposure time for a measurement image
- σ^{W}_{CRhijk} - initial standard deviation estimate of the signal level (in Rayleigh) from A2123.
- QL - parameter (from CDB) determining whether the observed intensity variation in the image is acceptable or not.

OUTPUT:

The output parameters are:

- $\overline{I^{TW}_{hij}}$ - the mean intensity image for the reduced window for the measurement being considered.
- $Flags^{W}_{hij}$ - the bad bin flags for the reduced window for the mean intensity image $\overline{I^{TW}_{hij}}$.

if the measurement is suitable for filter parameter determination.

Otherwise there is no output.

HYPOTHESIS OF APPLICABILITY:

The acceptable intensity variation during a measurement may be determined by considering the four sums of the images,

$$(I_{R_{hijl}} + I_{R_{hij(l+4)}}), l = 1, \ldots, 4 \quad \textbf{(EQ 8.13)}$$

for the eight-point measurement and

$$I_{R_{hijl_1}} + I_{R_{hijl_2}}, (l_1, l_2) \in \{ (1, 3), (2, 4), (5, 7), (6, 8) \} \quad \textbf{(EQ 8.14)}$$

for the double four-point measurement, to be independent determinations of the line of sight intensity. The sums above are correct as long as the current definition of the step size in the eight-point measurement, the double four-point and four-point measurments remains at $\frac{\pi}{4}, \frac{\pi}{2}$ and $\frac{\pi}{2}$ respectively. The root mean square (RMS) variation of these intensities relative to the square root of the mean intensity provides a measure which can be compared to a parameter (to be provided in the CDB) to determine the suitability of the measurement.

CRITERIA OF APPLICABILITY:

Condition to be applied to all measurements being tested for suitability for filter parameter determination.

TRANSFORMATION EQUATIONS:

See subroutines below.

Perform the following calculations for suitable image files:

$\forall$ h, j and i in the FP window

For the eight-point measurement

$$I^{TW}_{hij}(l) = Flags_{hijl}Flags_{hij(l+4)}\left(\frac{I_{R_{hijl}}\overset{+}{,}I_{R_{hij(l+4)}}}{2}\right), \tag{EQ 8.15}$$

$$\overline{\sigma^{W}_{hij}(l)} = 0.5Flags_{hijl}Flags_{hij(l+4)}\sqrt{(\sigma^{W}_{CRhijl})^{2} + (\sigma^{W}_{CRhij(l+4)})^{2}} \tag{EQ 8.16}$$

and

$$NB_{hij}(l) = Flags_{hijl}Flags_{hij(l+4)} \tag{EQ 8.17}$$

where $l = 1, \ldots, 4$

For the double four-point measurement

$$I^{TW}_{hij}(l) = Flags_{hijl}Flags_{hijl_2}\left(\frac{I_{R_{hijl_1}}\overset{+}{,}I_{R_{hijl_2}}}{2}\right), \tag{EQ 8.18}$$

$$\overline{\sigma^{W}_{hij}(l)} = 0.5Flags_{hijl_1}Flags_{hijl_2}\sqrt{\left(\sigma^{W}_{CRhijl_1}\right)^{2} + \left(\sigma^{W}_{CRhijl_2}\right)^{2}} \tag{EQ 8.19}$$

and

$$NB_{hij}(l) = Flags_{hijl_1}Flags_{hijl_2} \tag{EQ 8.20}$$

where $l = 1, \ldots, 4$, and $(l_1, l_2) \in \{(1,3), (2,4), (5,7), (6,8)\}$

For the four-point measurement

$$I^{TW}_{hij}(l) = Flags_{hijl_1}Flags_{hijl_2}\left(\frac{I_{R_{hijl_1}}\overset{+}{,}I_{R_{hijl_2}}}{2}\right), \tag{EQ 8.21}$$

$$\overline{\sigma^{W}_{hij}(l)} = 0.5Flags_{hijl_1}Flags_{hijl_2}\sqrt{\left(\sigma^{W}_{CRhijl_1}\right)^{2} + \left(\sigma^{W}_{CRhijl_2}\right)^{2}} \tag{EQ 8.22}$$

and

$$NB_{hij}(l) = Flags_{hijl_1}Flags_{hijl_2} \tag{EQ 8.23}$$

where $l = 1, \ldots, 2$, and $(l_1, l_2) \in \{(1,3), (2,4)\}$

The bad bin flags, $Flags_{hij}$ for this reduced window are determined as follows.

- For the eight point measurements and the double-four point measurements

$$Flags^{W}_{hij} = 1 \tag{EQ 8.24}$$

IF $\sum^{l_k} NB_{hij} l > 2$.

- For the four point measurements

$$Flags^{W}_{hij} = 1 \qquad \text{(EQ 8.25)}$$

IF $\sum_{l=1}^{l_k} NB_{hij}(l) = 2$.

For all good bins as defined by $Flags_{hij}$, calculate the mean intensity:

$$\overline{I^{TW}_{hij}} = \frac{\sum_{l=1}^{l_k} I^{TW}_{hij}(l)}{\sum_{l=1}^{l_k} NB_{hij}(l)} \qquad \text{(EQ 8.26)}$$

the standard deviation of the intensities:

$$\sigma^{W}_{I^{T}_{hij}} = \frac{\left[\sum_{l=1}^{l_k} NB_{hij}(l)\left(I^{TW}_{hij}(l) - \overline{I^{TW}_{hij}}\right)^{2}\right]^{1/2}}{\sum_{l=1}^{l_k} NB_{hij}(l)} \qquad \text{(EQ 8.27)}$$

and the mean standard deviation of the intensities

$$\sigma^{WM}_{hij} = \frac{\left[\sum_{l=1}^{l_k} NB_{hij}(l)\,\overline{\sigma^{W}_{hij}(l)}^{2}\right]^{1/2}}{\sum_{l=1}^{l_k} NB_{hij}(l)} \qquad \text{(EQ 8.28)}$$

where l_k=4 for the eight-point and double four-point measurements and 2 for the four-point measurement.

Calculate the ratio for each good bin in each field of view

$$Rat^{W}_{hij} = \frac{\sigma_{I^{W}_{Thij}}}{\sigma^{WM}_{hij}} \qquad \text{(EQ 8.29)}$$

and calculate its mean, excluding bad bins from the calculation, $\overline{Rat^{W}}$ over i, j, and h.

IF $\overline{Rat}^{W} > QL$ **THEN** the measurement is considered unsuitable for filter parameter determinations.

8.3 A2443 - Calculate filter parameters

FUNCTIONAL DESCRIPTION:

The wavelength of the peak transmission at normal incidence λ_0 and the effective refractive index is determined for measurements not rejected. This estimation is accomplished by minimizing the root mean square (RMS) difference between the measured intensity values and the filter model (based on the Lissberger formula) using a nonlinear least mean squares approach for two dimensions.

The quantities needed for the filter model are the Doppler shifted wavelengths of the emissions being observed, λ_{hij}^{m}, the angles through the filter corresponding to each pixel on the CCD, and the filter parameters, $(\Delta\lambda)_0$, the filter half width at half height, and *fexp*, the exponent describing the shape of the filter function.

INPUT:

The input parameters are:

- N_i - number of measurement bins or rows in the vertical.
- N_j - number of measurement bins or columns in the horizontal.
- *NVB* - bin dimension in the vertical in pixels.
- *NHB* - bin dimension in the horizontal in pixels.
- *NVO* - vertical offset of the measurement window from the bottom of the CCD in bins.
- *NHO* - horizontal offset of the measurement window from the outside edges of the CCD.
- NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.
- NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.
- θ_{hij}^{FpW} - the filter angles for each pixel in the reduced window (from A2441).
- $\overline{I_{hij}^{TW}}$ - the mean intensity image for the reduced window for the measurement being considered (from A24422).
- $Flags_{hij}^{W}$ - the bad bin flags for the reduced window for the mean intensity image $\overline{I_{hij}^{TW}}$ (from A24422).
- λ_0^{e} - An estimate of the wavelength of the peak transmission at normal incidence λ_0 (from the CDB).

- μ_e^e - An estimate of the effective refractive index μ_e (from the CDB).
- $(\Delta\lambda)_0^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- $fexp^A$ - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.
- λ_m, m=1,2,...,8 - the eight emission wavelengths contributing to the intensity measured with the O2 filter (from CDB).
- vps_{hij}^{Wp} - projected spacecraft velocity along line of sight, for all pixels in the reduced window (from A2221).
- vre_{hij}^{Wp} - velocity of the earth rotation at the tangent point on a latitude circle for all pixels in the reduced window (from A2221).
- c - the speed of light (= 2.99792459 10^8 m/s)(from CDB).
- $\tau(\theta)$ - the transmissivity of the filter as a function of the angle of incidence on the filter (provided as a function of three parameters in the CDB).
- $\vartheta_{R_h}^W$ - reference geodetic latitude of tangent point for the row of peak intensity in the reduced window for the measurement being considered (from $\vartheta_{R_{hi}}^W$ calculated in A221).
- Z_{hi} - the geodetic altitude for each row in the reduced window calculated at the middle image of each measurement and the column closest to the centre of each measurement window (from A221).
- D_N - the day number (number of days after January 1) of the measurement.

OUTPUT:

The output parameters are:

- λ_0 - The wavelength of the peak transmission at normal incidence of the filter.
- μ_e - The effective refractive index best characterizing the behaviour of the filter.
- UT_4 - the universal time associated with the fourth image of the measurement.

HYPOTHESIS OF APPLICABILITY:

For this algorithm it is assumed that interferometer effects can be eliminated by summing over N_k. This means that the deviation of the phase steps from $\frac{\pi}{4}$ (for N_k=8) or $\frac{\pi}{4}$ (for N_k=4) is negligable for the O_2 emissions being observed. Furthermore it is being assumed that the intensity variations across the CCD are attributable primarily to filter effects and that intensity variations due to the atmosphere are negligable either because these variations in fact are small, or because adjacent bins across a row view almost the same volume of air. Finally it is assumed that the intensity variation of the lines in the band being observed with WINDII do not vary greatly with temperature, so that atmospheric temperature variations will not dominate the intensity variations across the CCD.

CRITERIA OF APPLICABILITY:

Applied to all suitable O_2 measurements as determined by A2442.

TRANSFORMATION EQUATIONS:

The steps in this algorithm are:

1. Calculate the emission intensities in each row in the FP window, A24431.
2. Calculate the Doppler shifted wavelengths for each pixel in this window A24433. The velocity fields used here may have to be interpolated to a pixel by pixel basis at this point depending on how the velocities are calculated in A2221.
3. Calculate the mean observed intensity for each FOV, A24434.
4. Find the filter parameters λ_0 and μ_e which minimize the least mean square difference between the observed intensities and the model in the FP window (A24435).

8.3.1 A24431 - Calculation of the emission intensities in each row

FUNCTIONAL DESCRIPTION:

To calculate the filter parameters the intensities of each of the contributing lines is needed. These intensities are calculated by determining the peak intensities in each of the rows being used in each half of each field of view. These intensities are attributed to the ${}^{P}P(5)$ and ${}^{P}P(7)$ lines. The remaining lines are calculated relative to these intensities using constants which are a function of height, latitude and day number.

INPUT:

The input parameters are:

- $\overline{I_{hij}^{TW}}$ - the mean intensity image for the bins in the reduced window for the measurement being considered (from A24422).
- $\vartheta_{R_h}^{W}$ - reference geodetic latitude of tangent point for the row of peak intensity in the reduced window for the measurement being considered (from $\vartheta_{R_{hi}}^{W}$ calculated in A221).
- Z_{hi}^{W} - the geodetic altitude for each row in the reduced window calculated at the middle image of each measurement and the column closest to the centre of each measurement window (from A221).
- D_N - the day number (number of days after January 1) of the measurement.
- N_j - the number of measurement bins in the horizontal.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.

- $I_{rat}^{mW}\left(Z_{hi}^{W}, D_N, \vartheta_{R_h}^{W}\right)$ - the ratio of the intensity of the $^{P}Q(3)$, $^{P}P(3)$, $^{P}Q(5)$,and $^{P}P(5)$ lines to the $^{P}P(5)$ line and the ratio of the intensity of the $^{P}Q(7)$, $^{P}P(9)$, $^{P}Q(9)$ and $^{P}P(7)$ lines to the $^{P}P(7)$ line. The calculation of these ratios is described in A24432.

OUTPUT:

The output parameters are:

- IM_{hi}^{mW} - the intensities of the emission lines for each row being used for filter parameter determination.

HYPOTHESIS OF APPLICABILITY:

The maximum intensity in each half of each field of view in the *FP* windows is assumed to be a useful way of estimating the actual line of sight intensities of the $^{P}P(5)$ and $^{P}P(7)$ lines. The intensities of the remaining lines are assumed to be proportional to these lines. The proportionality is a function of height, latitude and day number. When absorption effects are unimportant, the ratio is calculated from quantum mechanical considerations for the $^{P}P(5)/^{P}Q(5)$ and $^{P}P(7)/^{P}Q(5)$ lines and derived from the Boltzman distribution at the temperature $T(Z_{hi})$ for the remaining lines. For heights where absorption effects are important these constants are determined from radiative transfer calculations. These constants involved in the calculation of these ratios are provided in the CDB.

CRITERIA OF APPLICABILITY:

This function is to be used for all filter parameter determinations.

TRANSFORMATION EQUATIONS:

For each field of view calculate the profiles of intensity ratios corresponding to the height profiles Z_{hi}^{W}, $\vartheta_{R_h}^{W}$ and D_N using A24432.

Define $W_{\frac{1}{2}} = \text{nearest integer} \geq \frac{N_j}{2}$

For Fov1

$$IM_{1i}^{6W} = \frac{max\left(\overline{I_{1ij}^{TW}}\right)}{NVB \bullet NHB}, j = 1 \text{ to } W_{\frac{1}{2}} \tag{EQ 8.30}$$

$$IM_{1i}^{4W} = \frac{max\left(\overline{I_{1ij}^{TW}}\right)}{NVB \bullet NHB}, j = W_{\frac{1}{2}} + 1 \text{ to } N_j \tag{EQ 8.31}$$

$$IM_{1i}^{mW} = IM_{1i}^{4W} \bullet I_{rat}^{mW}\left(Z_{hi}^{W}, D_N, \vartheta_{R_h}^{W}\right), m = 1 \text{ to } 3 \tag{EQ 8.32}$$

$$IM_{1i}^{mW} = IM_{1i}^{6} \bullet I_{rat}^{mW}\left(Z_{hi}^{W}, D_{N}, \vartheta_{R_h}^{W}\right), m = 5, 7 \text{ and } 8 \quad \textbf{(EQ 8.33)}$$

For Fov2

$$IM_{2i}^{6W} = \frac{max\left(\overline{I_{2ij}^{TW}}\right)}{NVB \bullet NHB}, j = W_{\frac{1}{2}} + 1 \text{ to } N_j \quad \textbf{(EQ 8.34)}$$

$$IM_{2i}^{4W} = \frac{max\left(\overline{I_{2ij}^{TW}}\right)}{NVB \bullet NHB}, j = 1 \text{ to } W_{\frac{1}{2}} \quad \textbf{(EQ 8.35)}$$

$$IM_{2i}^{mW} = IM_{2i}^{4W} \bullet I_{rat}^{mW}\left(Z_{hi}^{W}, D_{N}, \vartheta_{R_h}^{W}\right), m = 1 \text{ to } 3 \quad \textbf{(EQ 8.36)}$$

$$IM_{2i}^{mW} = IM_{2i}^{6} \bullet I_{rat}^{mW}\left(Z_{hi}^{W}, D_{N}, \vartheta_{R_h}^{W}\right), m = 5, 7 \text{ and } 8 \quad \textbf{(EQ 8.37)}$$

8.3.2 A24432 - Calculation of the emission intensity ratios

FUNCTIONAL DESCRIPTION:

In reality the intensity ratios are a function of time and tangent point location. To approximate this variation constants are provided in the CDB to calculate these intensity ratios. These constants consist of cubic spline coefficients to generate the height profiles of the intensity ratios at five latitudes for each of the twelve months of the year. The intensity ratios for a given day number, latitude and height are obtained by the linear interpolation in time and latitude of the height profiles calculated from the spline coefficients provided in the CDB. This function assumes the specific inputs ϑ, Z and D_N.

INPUT:

The input parameters are:

- ϑ - reference geodetic latitude of tangent point for each field of view in the measurement.
- Z - the geodetic altitude.
- D_N - the day number (number of days after January 1) of the measurement.
- D_{Nr}^{P} - the twelve day numbers (index r) at which CDB profiles are calculated (provided in the CDB).
- ϑ_{s}^{P} - the five geodetic latitudes (index s) at which profiles of intensity ratio are provided (from the CDB).
- $Z_{ref}(20)$ - the reference heights at which the knots of the cubic spline are located (in the CDB).
- $CS_{rat}^{m}(Z_{ref}, D_{Nr}^{P}, \vartheta_{s}^{P}, 2)$ - the coefficients of the cubic splines for calculating the line intensity ratios height profiles for the eight emissions of interest (provided in the

CDB). It contains the value of I_{rat}^{m} at the reference points and the spline coefficients at the reference points, hence the 2 in the expression CS_{rat}^{m}.

OUTPUT:
The output parameters are:

- $I_{rat}^{m}(Z, D_N, \vartheta)$ - the ratio of the intensity of the ${}^{P}Q(3)$, ${}^{P}P(3)$, ${}^{P}Q(5)$, and ${}^{P}P(5)$ lines to the ${}^{P}P(5)$ line and the ratio of the intensity of the ${}^{P}Q(7)$, ${}^{P}P(9)$, ${}^{P}Q(9)$ and ${}^{P}P(7)$ lines to the ${}^{P}P(7)$ line.

HYPOTHESIS OF APPLICABILITY:
It is assumed that the natural variations in the intensity ratios for the O_2 emissions may be adequately modelled through linear interpolations in time and latitude and as cubic splines in height.

CRITERIA OF APPLICABILITY:
This function is called by A24431 and A32.

TRANSFORMATION EQUATIONS:
The following steps are involved in this function:

1. Find the two day numbers, $D_{Nr_1}^{P}$ and $D_{Nr_2}^{P}$, which bracket D_N (remembering that the day numbers are cyclic).

2. Find the two latitudes $\vartheta_{s_1}^{P}$ and $\vartheta_{s_2}^{P}$ which bracket .

3. Calculate the intensity ratios at the input height, Z, at $I_{rat}^{m}\left(Z, D_{Nr_1}^{P}, \vartheta_{s_1}^{P}\right)$, $I_{rat}^{m}\left(Z, D_{Nr_1}^{P}, \vartheta_{s_2}^{P}\right)$, $I_{rat}^{m}\left(Z, D_{Nr_2}^{P}, \vartheta_{s_1}^{P}\right)$ and $I_{rat}^{m}\left(Z, D_{Nr_2}^{P}, \vartheta_{s_2}^{1\;P}\right)$, using the cubic splines, $CS_{rat}^{m}(Z_{ref}, D_{Nr}^{P}, \vartheta_{s}^{P})$ provided in the CDB.

4. The desired ratios are obtained by performing a linear interpolation between latitudes so that

$$I_{rat}^{m}\left(Z, D_{Nr_1}^{P}, \vartheta\right) = I_{rat}^{m}\left(Z, D_{Nr_1}^{P}, \vartheta_{s_1}^{P}\right) + \tag{EQ 8.38}$$

$$\frac{\vartheta - \vartheta_{s_1}^{P}}{\vartheta_{s_2}^{P} - \vartheta_{s_1}^{P}}\left(I_{rat}^{m}\left(Z, D_{Nr_1}^{P}, \vartheta_{s_2}^{P}\right) - I_{rat}^{m}\left(Z, D_{Nr_1}^{P}, \vartheta_{s_1}^{P}\right)\right) \tag{EQ 8.39}$$

and

$$I_{rat}^{m}\left(Z, D_{Nr_2}^{P}, \vartheta\right) = I_{rat}^{m}\left(Z, D_{Nr_2}^{P}, \vartheta_{s_1}^{P}\right) + \tag{EQ 8.40}$$

$$\frac{\vartheta - \vartheta_{s_1}^{P}}{\vartheta_{s_2}^{P} - \vartheta_{s_1}^{P}} \left(I_{rat}^{m}\left(Z, D_{Nr_2}^{P}\right), \vartheta_{s}^{2^{P}} \right) - I_{rat}^{m} Z, D_{Nr_2}^{P}, \vartheta_{s}^{1^{P}} \tag{EQ 8.41}$$

followed by a linear interpolation in day number so that: **(EQ 8.42)**

$$I_{rat}^{m}(Z, D_N, \vartheta) = I_{rat}^{m}\left(Z, D_{Nr_1}^{P}, \vartheta\right) + \tag{EQ 8.43}$$

$$\frac{D_N - D_{Nr_1}^{P}}{D_{Nr_2}^{P} - D_{Nr_1}^{P}} \left(I_{rat}^{m}\left(Z, D_{Nr_2}^{P}, \vartheta\right) - I_{rat}^{m}\left(Z, D_{Nr_1}^{P}, \vartheta\right) \right) \tag{EQ 8.44}$$

8.3.3 A24433 - Calculate the Doppler shifted wavelengths, λ_{hij}^{mpW}

FUNCTIONAL DESCRIPTION:

For each of the O_2 emissions being considered the Doppler shifted wavelength (due to the spacecraft velocity and earth rotation velocity) must be calculated for each pixel. in the *FP* window. This ensures that the filter function is calculated correctly.

INPUT:

The input parameters are:

- NM_h - index giving the row of maximum intensity (from A24421).
- N_i - number of measurement bins or rows in the vertical.
- N_j - number of measurement bins or rows in the horizontal.
- *NVB* - bin dimension in the vertical in pixels.
- *NHB* - bin dimension in the horizontal in pixels.
- *NVO* - vertical offset of the measurement window from the bottom of the CCD in bins.
- *NHO* - horizontal offset of the measurement window from the outside edges of the CCD in pixels.
- NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.
- NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.
- λ_m, $m=1, 2, \ldots, 8$ - the eight emission wavelengths contributing to the intensity measured with the O_2 filter (from CDB).
- vps_{hij}^{Wp} - projected spacecraft velocity along line of sight, for all pixels in the reduced window (from A2221).
- vre_{hij}^{Wp} - velocity of the earth rotation at the tangent point on a latitude circle for all pixels in the reduced window (from A2221).
- c - the speed of light (= $2.997925\ 10^{8}$ m/s)

OUTPUT:

The output parameters are:

- λ_{hij}^{mpW}, m=1, 2, ... , 8 - the Doppler shifted wavelengths for each pixel in the *FP* window.

HYPOTHESIS OF APPLICABILITY:

The emission wavelengths are assumed to be Doppler shifted by the spacecraft velocity and earth rotation velocity. The effect of the Doppler shift due to the wind relative to the earth is assumed to be negligable. The convention used here is that the Doppler shift is positive when the atmosphere is moving toward the spacecraft.

CRITERIA OF APPLICABILITY:

For all calculations of the filter parameters.

TRANSFORMATION EQUATIONS:

Depending on how the velocities, vsp_{hij}^{W} and vre_{hij}^{W} are calculated in A2221, quadratic interpolation may be required to generate the velocities vsp_{hij}^{Wp} and vre_{hij}^{Wp} on a pixel by pixel basis for the reduced window.

$$\lambda_{hij}^{mpW} = \lambda_m\left(1 - \frac{(vsp_{hij}^{Wp} + vre_{hij}^{Wp})}{c}\right) \qquad \textbf{(EQ 8.45)}$$

8.3.4 A24434 - Calculate the mean observed intensity

FUNCTIONAL DESCRIPTION:

The mean intensity of each field of view in the *FP* window is needed to provide a normalizing factor for the modelled filter intensities. This is calculated in this subroutine.

INPUT:

The input parameters are:

- $\overline{I_{hij}^{TW}}$ - the mean intensity image for the reduced window of the measurement being considered (from A24422).
- $Flags_{hij}^{W}$ - the bad bin flags for the reduced window for the mean intensity image $\overline{I_{hij}^{TW}}$ (from A24422).

OUTPUT:

The output parameter is:

- $\overline{I_{Mh}^{TW}}$ - the mean intensity for each field of view.

HYPOTHESIS OF APPLICABILITY:

The mean intensity for each field of view is determined by summing over all bins in the field of view and dividing by the number of bins.

CRITERIA OF APPLICABILITY:

For all calculations of the filter parameters.

TRANSFORMATION EQUATIONS:

Define N^F_{Rh} as the number of rows in each field of view in the *FP* window. The number of good bins in the reduced window is

$$NB_h = \sum_{i=1}^{N^F_{Rh}} \sum_{j=1}^{N_j} Flags^W_{hij} \qquad \text{(EQ 8.46)}$$

$$\overline{I^{TW}_{Mh}} = \frac{1}{NB_h} \sum_{i=1}^{N^F_{Rh}} \sum_{j=1}^{N_j} Flags^W_{hij} \overline{I^{TW}_{hij}} \qquad \text{(EQ 8.47)}$$

8.3.5 A24435 - Determine the filter parameters

FUNCTIONAL DESCRIPTION:

The filter parameters, λ_0 and μ_e are determined by minimizing in a least mean squares sense the difference between the intensity field in the *FP* window and an estimate of the intensity for this window obtained using the Lissberger formula.

INPUT:

The input parameters are:

- $\overline{I^{TW}_{hij}}$ - the mean intensity image for the measurement being considered (from A24422).
- $\overline{I^{TW}_{Mh}}$ - the mean intensity for each field of view (from A24434).
- $Flags^W_{hij}$ - the bad bin flags for the reduced window for the mean intensity image $\overline{I^{TW}_{hij}}$ (from A24422).
- θ^{FpW}_{hij} - the filter angles for each pixel in the reduced window being used for filter parameter determination (from A2441).
- $IM^{m^W}_{hi}$ - the intensities of the emission lines for each row being used for filter parameter determination (from A24431).
- $\lambda^{mp^W}_{hij}$, m=1, 2, ... , 8 - the Doppler shifted wavelengths for each pixel in the window being used for the filter determination (from A24433).

- λ_0^e - An estimate of the wavelength of the peak transmission at normal incidence (from the CDB).
- μ_e^e - An estimate of the effective refractive index (from the CDB).
- $(\Delta\lambda)_0^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- $fexp^A$ - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT:

The output parameters are:

- $\lambda_0^A(UT)$ - The wavelength of the peak transmission at normal incidence of the filter best characterizing the behaviour of the filter.
- $\mu_e^A(UT)$ - The effective refractive index best characterizing the behaviour of the filter.
- UT - the universal time of the measurement.

HYPOTHESIS OF APPLICABILITY:

The filter is assumed to be adequately described by the Lissberger formula.

CRITERIA OF APPLICABILITY:

To be applied to all suitable O_2 measurements as determined in A2442.

TRANSFORMATION EQUATIONS:

Determine and by minimizing in a least mean squares sense, using standard techniques (ie the NAG library), the merit function

$$MF = \sum_{hij} \left(\overline{I_{hij}^{TW}} - I_{hij}^{FW}(\lambda_0, \mu_e)\right)^2 \qquad \textbf{(EQ 8.48)}$$

with respect to these parameters. The sum is only over good bins as determined by $Flags_{hij}$. $I_{hij}^{FW}(\lambda_0, \mu_e)$ is the modelled intensity due to the m emissions at the ijth bin after transmission through the filter. The evaluation of this function is described below in A244351. The starting values for this minimization are λ_0^e and μ_e^e given in the CDB.

8.3.5.1 A244351- Calculation of the net intensity after passage through the filter

FUNCTIONAL DESCRIPTION:

This routine calculates the intensity incident on the hijth bin of the CCD as determined by the effect of the filter (omitting the Michelson effects). In it the intensity is first calculated on a pixel by pixel basis and then binned according to the binning used in the image being analysed. The mean intensity over each window in each field of view, $\overline{I^{FW}_{Mh}}$, is then calculated and along with the mean intensity of the observed intensities, $\overline{I^{TW}_{Mh}}$, used to normalize the result.

INPUT:

The input parameters are:

- $\overline{I^{TW}_{Mh}}$ - the mean intensity for each field of view (from A24434).
- θ^{FpW}_{hij} - the filter angles for each pixel in the reduced window being used for filter parameter determination (from A2441).
- IM^{mW}_{hi} - the intensities of the emission lines for each row being used for filter parameter determination (from A24431).
- λ^{mpW}_{hij}, m=1, 2, ... , 8 - the Doppler shifted wavelengths for each pixel in the window being used for the filter determination.
- λ_0 - the wavelength at peak transmission at normal incidence, an input parameter.
- μ_e - the effective refractive index, an input parameter.
- $(\Delta\lambda)^A_0$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- $fexp^A$ - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT:

The output parameters are:

- $I^{FW}_{hij}(\lambda_0, \mu_e)$ - the model intensity incident on the hij^th bin due to the filter alone.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the Lissberger formula provides an accurate model of the behaviour of the O_2 filter on WINDII.

CRITERIA OF APPLICABILITY:

To be used for all estimations of the filter parameters.

TRANSFORMATION EQUATIONS:

The steps in this function are:

1. Calculate the intensity $I^{FpmW}_{hij}(\lambda_0, \mu_e)$ at the CCD for each pixel in the reduced window being used for filter parameter determination, using

$$I^{FpmW}_{hij}(\lambda_0, \mu_e) = IM^{mW}_{hi} \times F(\lambda_0, \mu_e; \theta^{FpW}_{hij}, \lambda^{mpW}_{hij}, (\Delta\lambda)^A_0, fexp^A) \qquad \textbf{(EQ 8.49)}$$

image being analysed. The mean intensity over each window in each field of view, $\overline{I_{Mh}^{FW}}$, is then calculated and along with the mean intensity of the observed intensities, $\overline{I_{Mh}^{TW}}$, used to normalize the result.

INPUT:

The input parameters are:

- $\overline{I_{Mh}^{TW}}$ - the mean intensity for each field of view (from A24434).
- θ_{hij}^{FpW} - the filter angles for each pixel in the reduced window being used for filter parameter determination (from A2441).
- IM_{hi}^{mW} - the intensities of the emission lines for each row being used for filter parameter determination (from A24431).
- λ_{hij}^{mpW}, $m=1, 2, \ldots, 8$ - the Doppler shifted wavelengths for each pixel in the window being used for the filter determination.
- λ_0 - the wavelength at peak transmission at normal incidence, an input parameter.
- μ_e - the effective refractive index, an input parameter.
- $(\Delta\lambda)_0^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- $fexp^A$ - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT:

The output parameters are:

- $I_{hij}^{FW}(\lambda_0, \mu_e)$ - the model intensity incident on the hij^th bin due to the filter alone.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the Lissberger formula provides an accurate model of the behaviour of the O_2 filter on WINDII.

CRITERIA OF APPLICABILITY:

To be used for all estimations of the filter parameters.

TRANSFORMATION EQUATIONS:

The steps in this function are:

1. Calculate the intensity $I_{hij}^{FpmW}(\lambda_0, \mu_e)$ at the CCD for each pixel in the reduced window being used for filter parameter determination, using

$$I_{hij}^{FpmW}(\lambda_0, \mu_e) = IM_{hi}^{mW} \times F(\lambda_0, \mu_e; \theta_{hij}^{FpW}, \lambda_{hij}^{mpW}, (\Delta\lambda)_0^A, fexp^A) \qquad \textbf{(EQ 8.49)}$$

The evaluation of F is given in A244352.

2. Calculate the intensity due to each emission at each bin Ihij^F , m , W(,) by summing over the pixels contributing to each bin

$$I_{hij}^{FmW}(\lambda_0, \mu_e) = \sum_{pixels} I_{hij}^{FpmW}(\lambda_0, \mu_e) \qquad \textbf{(EQ 8.50)}$$

3. Calculate the net intensity at each bin $I_{hij}^{FW*}(\lambda_0, \mu_e)$ by summing over the contributing emissions

$$I_{hij}^{FW}(\lambda_0, \mu_e) = \sum_{m} I_{hij}^{FmW}(\lambda_0, \mu_e) \qquad \textbf{(EQ 8.51)}$$

4. Calculate the mean intensity in each window of each field of view $\overline{I_{Mh}^{FW}}$ from the model data using only good bins as determined by $Flags_{hij}$.

$$\overline{I_{Mh}^{FW}} = \frac{1}{\sum\limits_{i=1}^{N_R^F}\sum\limits_{j=1}^{N_j} Flags_{hij}} \sum_{i=1}^{N_R^F}\sum_{j=1}^{N_j} I_{hij}^{FW*}(\lambda_0, \mu_e) \qquad \textbf{(EQ 8.52)}$$

where N_R^F is the number of rows in the measurement window being used for filter parameter determination and is given by:

$$N_R^F = \delta R- + \delta R+ + 1 \qquad \textbf{(EQ 8.53)}$$

5. Normalize the model data using the mean intensities from the model data $\overline{I_{Mh}^{FW}}$ and the mean intensities from the observations $\overline{I_{Mh}^{TW}}$.

$$I_{hij}^{FW}(\lambda_0, \mu_e) = \frac{\overline{I_{Mh}^{TW}}}{\overline{I_{Mh}^{FW}}} I_{hij}^{FW*}(\lambda_0, \mu_e) \qquad \textbf{(EQ 8.54)}$$

8.3.5.2 A244352 - Calculation of the filter function *F*

FUNCTIONAL DESCRIPTION:

The Lissberger formula is used to calculate the intensity for a prescribed set of input parameters. This function is called by A244351 and A311.

INPUT:

- θ - the input angle through the filter.
- λ - the wavelength at which the filter function is to be evaluated.
- $\tau(\theta)$ - the transmissivity of the filter as a function of the angle of incidence on the filter (provided as a function of three parameters, τ_1, τ_2, and τ_3, in the CDB).
- λ_0 - the wavelenght of peak transmission at normal incidence, an input parameter.
- μ_e - the effective refractive index, an input parameter.
- $(\Delta\lambda)_0^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- $fexp^A$ - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT:

The output parameters are:

- $F(\lambda_0, \mu_e; \theta, \lambda, (\Delta\lambda)_0^A, fexp^A)$ - the filter function.

HYPOTHESIS OF APPLICABILITY:

The Lissberger formula is an adequate description of the O_2 filter.

CRITERIA OF APPLICABILITY:

Used for all calculations of the filter function in filter parameter determinations.

TRANSFORMATION EQUATIONS:

The filter function is calculated as follows:

Calculate the peak transmissivity of the filter:

$$\tau(\theta) = \tau_1 + \tau_2\theta + \tau_3\theta^2 \tag{EQ 8.55}$$

Calculate the filter function

$$F(\lambda_0, \mu_e; \theta, \lambda, (\Delta\lambda)_0^A, fexp^A) \tag{EQ 8.56}$$

$$= \frac{\tau(\theta)}{1 + \left|\left[\frac{2(\lambda - \lambda_0)}{(\Delta\lambda)_0^A} + \frac{\lambda_0}{(\Delta\lambda)_0^A}\frac{\theta^2}{\mu_e^2}\right]\right|^{fexp^A}} \tag{EQ 8.57}$$

8.4 A2444 - Interpolate to obtain daily filter parameters

FUNCTIONAL DESCRIPTION:

The daily record of filter parameters is used to provide a functional fit for these parameters. This fit is then used to provide the filter parameters λ_0 and μ_e at any time during the day.

INPUT:

The input parameters are:

- $\lambda_0^A(UT)$ - The wavelength of the peak transmission at normal incidence of the filter best characterizing the behaviour of the filter.
- $\mu_e^A(UT)$ - The effective refractive index best characterizing the behaviour of the filter.

OUTPUT:

The output parameters are:

- $\lambda_0^A(UT)$ - the coefficients of the quadradic expression giving the filter parameter as a function of universal time (r=1,,3). The coefficients are a function of aperture.
- $\mu_e^A(UT)$ - the coefficients of the quadradic expression giving the filter parameter as a function of universal time (r=1,,3). The coefficients are a function of aperture.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the variation of the filter parameters with time is smooth and adequately described using a quadratic function.

CRITERIA OF APPLICABILITY:

To be applied each O_2 day.

TRANSFORMATION EQUATIONS:

- Using all the $\lambda_0^A(UT)$ for each aperture, A, calculate the quadratic fit for λ_0 verses UT, the coefficients for this fit being $C_r^{\lambda_0 A}$ (r=1,,3).
- Using all the $\mu_e^A(UT)$ for each aperture, calculate the quadratic fit for μ_e verses UT, the coefficients for this fit being $C_r^{\mu_e^A}$ (r=1,,3).

Note: the coefficients of the quadratic fit are designated as follows:

$$\lambda_0^A(UT) = C_1^{\lambda_0 A} + C_2^{\lambda_0 A} \times UT + C_3^{\lambda_0 A} \times UT^2 \qquad \textbf{(EQ 8.58)}$$

with a similar form for the remaining fits.

Part III

A3 - Data Reduction

FUNCTIONAL DESCRIPTION:

As derived in the document, "The O_2 Algorithm for WINDII - Conceptual Summary", the general expression for the intensity measured at the hijth bin on the kth measurement is given by

$$I^T_{hijk} = A(x_{hijk})\left[\sum_m a^m_{hij} J1^m_{hi} + \sum_m b^m_{hijk} J2^m_{hi} - \sum_m c^m_{hijk} J3^m_{hi}\right] + I^B_{hi} \quad \textbf{(EQ 8.59)}$$

where

$$a^m_{hij} = \left.\overline{F^{mp}_{hij}}\right|_{bin},$$

$$b^m_{hijk} = \left.\overline{U^{Imp}_{hij} F^{mp}_{hij} \cos\Phi^{AImp}_{hijk}}\right|_{bin},$$

$$c^m_{hijk} = \left.\overline{U^{Imp}_{hij} F^{mp}_{hij} \sin\Phi^{AImp}_{hijk}}\right|_{bin},$$

$$J1^m_{hi} = \int_{L_{hi}} n_h(z)\, C^m_1 e^{-\frac{C^m_2}{T_h(z)}}\, dz, \quad \textbf{(EQ 8.60)}$$

$$J2^m_{hi} = \int_{L_{hi}} n_h(z)\, C^m_1 e^{-\frac{C^m_2}{T_h(z)}}\, V_{S_h}(z) \cos\phi_h(z)\, dz \text{ and}$$

$$J3^m_{hi} = \int_{L_{hi}} n_h(z)\, C^m_1 e^{-\frac{C^m_2}{T_h(z)}}\, V_{S_h}(z) \sin\phi_h(z)\, dz.$$

m is an index labelling the emission line in the band.

L_{hi} is the path through the atmosphere viewed by the hi^{th} row.

F^{mp}_{hij} is the filter transmittance for the hij^{th} pixel and m^{th} emission line.

$n_h(z)$ is the number density of the excited state of the transition under consideration as a function of height z.

$T_h(z)$ is the atmospheric temperature at height z.

C^m_1, C^m_2 are constants giving the appropriate functional relationship between the temperature and line intensity.

U^{Imp}_{hij} is the instrument visibility effect associated with the interferometer for the hij^{th} pixel.

$V_{S_h}(z$ is the spectral visibility effect associated with the line width and hence Doppler temperature.

Φ_{hijk}^{AImp} is the instrument phase associated with the interferometer for the hij^th pixel and includes the spacecraft velocity, the earth rotation velocity, the background phase distribution associated with the instrument and the phase step associated with the k^{th} step.

$\phi_h(z)$ is the phase associated with Doppler shifts in the atmospheric emissions due to atmospheric motions.

I_{hij}^{B} is the intensity associated with the background (baffle scattered or direct).

$A(x_{hijk})$ is a function giving the intensity variation of the emission along the tangent point track. The two functional forms for A implemented for this algorithm are $A=1$ or $A=1+\alpha x_{hijk}$.

x_{hijk} is a parameter giving the position of the tangent point associated with the $hijk^{th}$ bin.

$|_{bin}$ implies the average is taken over all the pixels in the bin.

and the atmosphere is assumed to be horizontally homogeneous.

The quantites of interest are the values of the wind, temperature and volume emission rate (for O_2, the band volume emission rate) as a function of height. For the O_2 algorithm these quantities are derived in a two step procedure. In the first step the line of sight quantities, $J1_{hi}$, $J2_{hi}$ and $J3_{hi}$ are derived using the intensity measurements for each row. This step involves the calculation of the weighting factors followed by an inversion of the above expression to obtain these quantities. They are then inverted to obtain the profiles of interest. The details of each of these steps is outlined in the subroutines which follow.

INPUT:

See the subroutines which follow.

OUTPUT:

The output parameters are:

- B_{O_2hi} - the band volume emission rate profile for the O_2 band being observed.
- $\sigma_{B_{O_2}hi}$ - estimate of the error in B_{O_2hi}.
- $T_{rothi}^{O_2}$ - the rotational temperature profile.
- $\sigma_{T_{rot}^{O_2}hi}$ - estimate of the error in $T_{rothi}^{O_2}$.

- w_{hi} - the horizontal wind profile.
- $\sigma_{w_{hi}}$ - estimate of the error in w_{hi}.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the atmosphere may be treated as being locally horizontally homogeneous (over the region of the atmosphere sampled during the course of one measurement).

CRITERIA OF APPLICABILITY:

This function is to be applied to all O_2 measurements.

TRANSFORMATION EQUATIONS:

The structure of this algorithm is as follows:

1. Calculate the instrument weighting factors, a^m_{hij}, b^m_{hijk}, c^m_{hijk} and x_{hijk}.
2. Invert the intensity measurements for each row to obtain the apparent quantities, $J1_{hi}$, $J2_{hi}$ and $J3_{hi}$.
3. Invert the apparent quantities to obtain the atmospheric profiles of interest.

CHAPTER 9

A31 - Calculate instrument weighting factors

FUNCTIONAL DESCRIPTION:

In this function, the algorithms to be used to calculate the parameters a^{m}_{hij}, b^{m}_{hijk}, c^{m}_{hijk} and x_{hijk} are described. To obtain the former three quantities, the instrument parameters are calculated on a pixel by pixel basis and then averaged over the measurement bins. The latter quantity is calulated on a bin by bin basis using the viewing geometry of the measurement.

INPUT:

See the subroutines below.

OUTPUT:

The output parameters are:

- a^{m}_{hij} - constant giving the instrument weighting associated with the constant intensity term in the expression for the intensity incident on the CCD.
- b^{m}_{hijk} - constant giving the instrument weighting associated with the cosine term in the expression for the intensity incident on the CCD.
- c^{m}_{hijk} - constant giving the instrument weighting associated with the sine term in the expression for the intensity incident on the CCD.
- x_{hijk} - a parameter giving the position of the tangent point associated with the hijk^th bin

HYPOTHESIS OF APPLICABILITY:

The filter/Michelson combination is assumed to provide a weighting of the apparent quantities which depends on the bin position and phase step. It is this variation in the weighting which permits the unambiguous determination of the apparent quantities from each measurement. It is assumed that the instrument parameters are well enough known that this weighting may be calculated to sufficient accuracy that the uncertainty in the derived atmospheric quantities is small enought that they are geophysically relevant.

CRITERIA OF APPLICABILITY:

This function is used for all O_2 measurements.

TRANSFORMATION EQUATIONS:

The steps in the calculation of the instrument weighting functions is as follows:

1. Calculate the filter transmission for each of the relevant emissions for all the pixels in the measurement field of view.

2. Calculate the net instrument phase due to all factors as a function of pixel position in the measurement field of view and phase step.

3. Calculate the instrument visibility as a function of pixel position in the measurement field of view.

4. Produce the constants a^m_{hij}, b^m_{hijk} and c^m_{hijk} by evaluating the appropriate functions of the quantities in items 1 to 3 above and then summing over the pixels contributing to the hijkth bin.

5. Calculate the value of x_{hijk} for each bin in the measurement.

9.1 A311 - Calculate filter transmission

FUNCTIONAL DESCRIPTION:

In this subroutine the O_2 filter transmission for all the pixels in the observation window are calculated using the Lissberger formula, equation 8.1.

INPUT:

The input parameters are:

- N_i - number of mesurement bins or rows in the vertical.
- N_j - number of mesurement bins or rows in the horizontal.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.
- NVO - vertical offset of the measurement window from the bottom of the CCD in bins.
- NHO - horizontal offset of the measurement window from the outside edges of the CCD.
- NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.
- NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.

- θ_{hij}^{Fp} - the filter angles for each pixel on the CCD (from A2441).
- Z_{hijk} - the geodetic altitude for each bin.
- $C_r^{\lambda_0 A}$ - the coefficients of the quadradic expression giving the filter parameter λ_0 as a function of universal time ($r = 1, \dots, 3$). The coefficients are a function of aperture.
- $C_r^{\mu_e A}$ - the coefficients of the quadradic expression giving the filter parameter μ_e as a function of universal time ($r = 1, \dots, 3$). The coefficients are a function of aperture (from A2444).
- $(\Delta\lambda)_0^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture (from A2444).
- $fexp^A$ - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.
- λ_m, $m = 1, 2, \dots, 8$ - the eight emission wavelengths contributing to the intensity measured with the O_2 filter (from CDB).
- vps_{hij}^p - projected spacecraft velocity along line of sight, from A2221.
- vre_{hij}^p - velocity of the earth rotation at tangent point on a latitude circle from A2221.
- c - the speed of light (= 2.99792459 10^8 m/s)

OUTPUT:

The output parameters are:

- F_{hij}^{mp} - the filter transmission for each wavelength at each pixel in the measurement window.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the Lissberger formula adequately describes the behaviour of the O_2 filter.

CRITERIA OF APPLICABILITY:

To be used in the analysis of each O_2 measurement.

TRANSFORMATION EQUATIONS:

The steps in the calculation of the filter transmission function are:

1. Select the angles of incidence on the filter for each pixel in the measurement window.

2. Determine the Doppler shifted wavelengths λ_{hij}^{mp}, for the eight O_2 emissions, contributing to the intensity on the CCD as done in A24433, but for the full measurement window.

3. Determine the filter transmission for each pixel in the measurement window and for the eight emissions of interest by:

(a) Calculating appropriate λ_0 and μ_e for the universal time of the measurement the coefficients $C_r^{\lambda_0 A}$ or $C_r^{\mu_e A}$ as appropriate. See A2444 for a description of the evaluation of these parameters.

(b) Calculate F_{hij}^{mp} using the function defined in A244352.

$$F_{hij}^{mp} = F\lambda_0, \mu_e; (\Delta\lambda)_0^A, fexp^A, \theta_{hij}^{Fp}, \lambda_{hij}^{mp} \qquad \textbf{(EQ 9.1)}$$

9.1.1 A3111 - Determine the filter transmission

FUNCTIONAL DESCRIPTION:

This routine calculates the transmission for each of the eight emissions of interest for all the pixels in the measurement window. The Lissberger function is used for this calculation.

INPUT:

The input parameters are:

- θ_{hij}^{Fp} - the filter angles for each pixel in the measurement window.
- λ_{hij}^{mp}, m=1, 2, ... , 8 - the Doppler shifted wavelengths for each pixel in the measurement window.
- $C_r^{\lambda_0 A}$ - the coefficients of the quadradic expression giving the filter parameter λ_0 as a function of universal time (r = 1, ... , 3). The coefficients are a function of aperture.
- $C_r^{\mu_e A}$ - the coefficients of the quadradic expression giving the filter parameter μ_e as a function of universal time (r =1, ... , 3). The coefficients are a function of aperture.
- $(\Delta\lambda)_0^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- $fexp^A$ - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.
- UT - the universal time of the measurement.

OUTPUT:

The output parameters are:

- F_{hij}^{mp} - the filter transmission for each wavelength at each pixel in the measurement window.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the Lissberger % formula provides an accurate model of the behaviour of the O_2 filter on % WINDII.

CRITERIA OF APPLICABILITY:

To be used for all O_2 % measurements.

TRANSFORMATION EQUATIONS:

The steps in this function are:

Calculate appropriate and for the % universal time of the measurement from either of the functions FltN or % FltD as appropriate. See A2444 for a description of the evaluation of these % parameters. %

Calculate Fhij^m , p using the function defined in % A244352. % % Fhij^m , p = F (,;( ) % ^A,fexp^A,^F , p, ^m , phij) % %

9.2 A312 - Prepare instrument phase files

FUNCTIONAL DESCRIPTION:

The contribution to the observed phase from all sources other than the atmospheric wind relative to the earth must be determined in order to unambiguously determine this quantity. In this routine two components to this contribution namely the phase steps and the instrument phase excluding the phase step (see A221, equation 5.2 for definitions of the phase quantities) are determined for each pixel in the measurement window and for each emission.

INPUT:

The input parameters are:

- $\phi^{Ap}_{Bhi}(a^{A}_{0hi}, a^{A}_{1hi}, a^{A}_{2hi}, a^{A}_{3hi}, a^{A}_{4hi}, a^{A}_{5hi})$ - an array of 240 x 6 x 2 parameters for each row and FOV giving the expansion coefficients for a 5th order polynomial fit to the phase variation across each row in each field of view on the CCD. This is provided in the CDB.
- ϕ^{Am}_{ZW} is the phase difference between the calibration phase and the phase of the mth emission as measured on the ground (provided in CDB).
- ϕ^{m}_{OFFh} is the phase difference between the calibration phase in space and the calibration phase on the ground (from A2223).
- $\delta\phi_{hijk}(\lambda^{6}p)$ is the phase step associated with the mirror step for the 6th emission (from A2224).
- ϕ^{mp}_{vhij} is the phase associated with the spacecraft velocity and rotation of the earth for the mth emission (from A222).
- N_i - number of measurement bins or rows in the vertical.
- N_j - number of measurement bins or rows in the horizontal.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.

- *NVO* - vertical offset of the measurement window from the bottom of the CCD in bins.
- *NHO* - horizontal offset of the measurement window from the outside edges of the CCD in pixels.
- NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.
- NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.

OUTPUT:

The output parameters are:

- ϕ^{mp}_{hij} - the instrument phase excluding the phase step for each emission for all pixels in the measurement window.
- $\delta\phi^{6p}_{hijk}$ - the phase steps for the $^{P}P(7)$ (m=6) emission for all pixels in the measurement window.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the form of the phase variation across the CCD remains constant for all emissions involved in this algorithm and for phase drifts associated with temperature variations in the interferometer. This permits the phase field to be described using a polynomial fit provided in the CDB. The zero wind and the interferometer phase drift are then single numbers rather than arrays. The phase associated with the spacecraft velocity, ϕ^{m}_{vhij} and the phase step, $\delta\phi_{hijk}(\lambda^{6})$ may need to be calculated using quadratic interpolation depending on how they were calculated in A2222 and A2224 respectively. It is assumed that the error introduced by such a procedure if undertaken is minimal.

CRITERIA OF APPLICABILITY:

This function is applied to all O_2 measurements.

TRANSFORMATION EQUATIONS:

The steps in calculating the instrument phase are as follows:

1. Calculate the phase distribution across the field as measured on the ground, using the coefficients in ϕ^{Ap}_{Bhi} (from CDB),

$$\phi^{Ap}_{Ghij} = a^{A}_{0hi} + a^{A}_{1hi}j + a^{A}_{2hi}j^{2} + a^{A}_{3hi}j^{3} + a^{A}_{4hi}j^{4} + a^{A}_{5hi}j^{5} \qquad \textbf{(EQ 9.2)}$$

for $i, j \in$ all pixels in the measurement window.

2. If needed (depending on how the phase associated with the spacecraft velocity and earth's rotation is calculated in A2222) calculate, ϕ^{mp}_{vhij}, for all pixels in the measurement window by quadratic interpolation.

3. If needed (depending on how the phase variation of the phase step across the field was calculated in A2224) calculate, (^6), for all pixels in the measurement window by quadratic interpolation.

4. Calculate the instrument phase, excluding the phase step, ϕ^{mp}_{hij}, for all pixels in the measurement window where

$$\phi^{mp}_{hij} = \phi^{Ap}_{Ghij} + \phi^{Am}_{ZWh} + \phi^{m}_{OFFh} + \phi^{mp}_{vhij}. \qquad \textbf{(EQ 9.3)}$$

$$\phi_G + \phi_Z + (\phi_F - \phi_G)_{AVG} + \phi_\nu$$

9.3 A313 - Prepare instrument visibility files

FUNCTIONAL DESCRIPTION:

The instrumental visibility is currently tabulated in the CDB for a 1 by 5 binning. This data set is used to determine the visibility on a pixel by pixel basis. This is accomplished simply by assigning the CDB visibility to all pixels within a given bin. The instrument visibility is assumed to be the same for all the emissions of interest.

INPUT:

The input parameters are:

- $U^{A}_{CDB_{hpq}}$ - the instrument visibility from the CDB in CDB bins.
- N_i - number of measurement bins or rows in the vertical.
- N_j - number of measurement bins or rows in the horizontal.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.
- NVO - vertical offset of the measurement window from the bottom of the CCD in bins.
- NHO - horizontal offset of the measurement window from the outside edges of the CCD in pixels.
- NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.
- NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.

OUTPUT:

The output parameter is:

- U^{Ap}_{hij} - the instrument visibility for every pixel in the measurement window.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the CDB instrument visibility for each pixel in a CDB bin is equal to the CDB vivibility of that bin. Furthermore it is assumed that the instrument visibility is independent of wavelength over the wavelength range associated with the O_2 emissions viewed.

CRITERIA OF APPLICABILITY:

This function is to be applied to all O_2 measurements.

TRANSFORMATION EQUATIONS:

$$U^{Ap}_{hij} = U^{A}_{CDB_{hpq}} \qquad \textbf{(EQ 9.4)}$$

where *hij* ranges through all pixels in each CDB bin.

9.4 A314 - Calculate the weighting factors

FUNCTIONAL DESCRIPTION:

The weighting factors are found by calculating a^{m}_{hij}, b^{m}_{hijk} and c^{m}_{hijk} on a pixel by pixel basis and then summing over the instrument binning to obtain the quantities of interest. The weighting factors are defined in equation 8.46. **UPDATE**

INPUT:

The input parameters are:

- ϕ^{mp}_{hij} - the background phase for each emission for all pixels in the measurement window excluding the phase associated with the phase step (from A312).
- $\delta\phi^{6p}_{hijk}$ - the phase steps for the $^{P}P(7)$ (m=6) emission for all pixels in the measurement window (from A312).
- U^{Ap}_{hij} - the instrument visibility for every pixel in the measurement window (from A313).
- F^{mp}_{hij} - the filter tranmission for each wavelength at each pixel in the measurement window (from A311).
- λ_m, m=1, 2, ... , 8 - the eight emission wavelengths contributing to the intensity measured with the O_2 filter (from CDB).
- N_i - number of measurement bins or rows in the vertical.
- N_j - number of measurement bins or rows in the horizontal.
- *NVB* - bin dimension in the vertical in pixels.
- *NHB* - bin dimension in the horizontal in pixels.

OUTPUT:

The output parameters are:

- a^{m}_{hij} - the weighting factor for each bin in the measurement window for the apparent quantities J^{m}_{1hi}.
- b^{m}_{hijk} - the weighting factor for each bin in the measurement window for the apparent quantities J^{m}_{2hi}.

- c^{m}_{hijk} - the weighting factor for each bin in the measurement window for the apparent quantities J^{m}_{3hi}.

HYPOTHESIS OF APPLICABILITY:

It is assumend that the weighting factors for each measurement bin are obtainable from an average over all the pixels in the bin of their values calculated on a pixel by pixel basis.

CRITERIA OF APPLICABILITY:

This function is to be applied to all O_2 measurements.

TRANSFORMATION EQUATIONS:

1. Calculate the weighting factors for all pixels in the measurement window.

$$a^{mp}_{hij} = F^{mp}_{hij} \quad \textbf{(EQ 9.5)}$$

$$b^{mp}_{hijk} = F^{mp}_{hij} U^{Ap}_{hij} \cos\left(\phi^{mp}_{hij} + \frac{\lambda_6}{\lambda_m} \delta\phi^{6p}_{hijk}\right) \quad \textbf{(EQ 9.6)}$$

$$c^{mp}_{hijk} = F^{mp}_{hij} U^{Ap}_{hij} \sin\left(\phi^{mp}_{hij} + \frac{\lambda_6}{\lambda_m} \delta\phi^{6p}_{hijk}\right) \quad \textbf{(EQ 9.7)}$$

2. Calculate the weighting factors for each measurement bin by averageing over all the pixels in the bin.

$$N_p = NVB \times NHB \quad \textbf{(EQ 9.8)}$$

$$a^{m}_{hij} = \frac{1}{N_p} \sum_{pixels} a^{mp}_{hij} \quad \textbf{(EQ 9.9)}$$

$$b^{m}_{hijk} = \frac{1}{N_p} \sum_{pixels} b^{mp}_{hijk} \quad \textbf{(EQ 9.10)}$$

$$c^{m}_{hijk} = \frac{1}{N_p} \sum_{pixels} c^{mp}_{hijk} \quad \textbf{(EQ 9.11)}$$

9.5 A315 - Calculate the relative tangent point position for each bin

FUNCTIONAL DESCRIPTION:

The satellite motion and the viewing geometry of WINDII results in each bin viewing a slightly different region of the atmosphere. If there is an intensity gradient in the atmosphere then each bin will view a slightly different intensity. The linear portion of such gradients may be taken into account by allowing the line of sight intensity to vary linearly with the tangent point position along the satellite track. The purpose of this function is to calculate a relative tangent point position for each measurement bin. In developing the algorithm to calculate the relative tangent point position, account was taken of the following considerations.

1. At the present time, when taking intensity gradients into account, only a one-dimensional fit is desired.
2. For a given image the intensity across a row is a function of the intensity gradient at approximately 45^ or 135^ (depending on the field of view) to the satellite track (ie perpendicular to the line of sight of each field of view).
3. For a given bin, the progression of intensity measurements associated with the mirror stepping (ie k=1,2,,8) is a function of any intensity gradients which might exist parallel to the satellite track at the tangent point track associated with that bin.
4. The intensity gradients which might affect the measured intensities in points 2 and 3 above are neither parallel nor orthogonal to each other.
5. For bins with heights larger than or equal to two pixels and exposure times of 2-3 seconds the length of the atmospheric path through the tangent point volume is larger than the distance sampled in the atmosphere across a given image or along the tangent point track.

To account for these factors, it was concluded that the relative tangent point position for each bin in the i^{th} row should be the point where the line of sight of that bin intersects a line extending roughly between the tangent point positions of bin $i, j = 1, k = 1$ and $i, j = N_j$ and $k = N_k$ for each field of view. More specifically, this line is determined as the line which minimizes, in a least mean squares sense, the average magnitude of the distance of all the tangent point positions in the i^th row in the measurement from that line.

INPUT:

The input parameters are:

- t_{exp} - the exposure time of each measurement.
- $V_{SAT}(3)$ - the spacecraft velocity at the time of the k_m^{th} image where $k_m = 5$ for the eight-point or double four-point measurements or $k_m = 3$ for the four-point measurement. This is generated by a call to the orbit attitude services routine, OA_SAT_ORB as in A2221.
- Z_{hijk} - geodetic tangent point altitude for each bin.
- Z_{satk_m} - the distance of the satellite from the centre of the earth at the time of the k_m^{th} image. Generated using P_{sat} (3) which is obtained by calling the orbit attitude services routine, OA_SAT_ORB. $Z_{satk_m} = |P_{sat}(3)|$
- $R_{E,h}$ - the radius of the earth at the tangent point associated with the bin in the middle of each measurement window at the k_m^{th} step, k_m defined as above.
- NHB - bin dimension in the horizontal in pixels.

- DP - nominal angular diameter of the solid angle subtended by a pixel (from CDB).
- $VECI_{hijk}(c)$ - direction cosine array in ECI coordinates for the line of sight for each bin in each FOV.
- N_i - number of measurement bins or rows in the vertical.
- N_j - number of measurement bins or rows in the horizontal.
- N_k - number of images in the measurement.

OUTPUT:

The output parameter is:

- x_{hijk} - the relative tangent point position for each bin in the measurement.

HYPOTHESIS OF APPLICABILITY:

It is assumed that the shell of atmosphere sampled during a measurement by all the bins in any given row may be approximated as a plane, coplanar with the tangent point plane associated with the bin in the middle of the row under consideration and for the middle image in the measurement. This however is only true if roll and curvature correction is done. In this case all $Z_{hijk} = Z_{hi}$. The satellite velocity and viewing geometry is assumed to be constant during the measurement and characterized by the conditions at the middle image of the measurement. With these assumptions the tangent points in a given row for each image in the measurement may be considered to sample the atmosphere in a line across this plane, with the line corresponding to each image remaining parallel to the lines associated with the other images.

CRITERIA OF APPLICABILITY:

This function is to be applied to all O_2 measurements for which linear intensity variations are to be considered.

TRANSFORMATION EQUATIONS:

The following steps are required to calculate the relative tangent point positions during a measurement. Here $k_m = 5$ for the eight-point or double four-point measurements or $k_m = 3$ for the four-point measurement and jm is the index of the column at the centre of the field of view.

1. Calculate the slope m_s in the reference plane (relative to a coordinate system in that plane centred at the position of the centre of the row halfway through the measurement, x-axis parallel to the velocity vector) of the line, L_M, minimizing the distance of the tangent point positions from itself. We note that relative to the chosen origin the tangent point corresponding to the hijkth bin are at coordinates (x^t_{hijk}, y^t_{hijk}) where

$$x^t_{hijk} = FG_{sd}\left(j - \frac{(N_j+1)}{2}\right)\frac{C_1 L_{si}}{N_j}\left|\sin\alpha_{hi}\right| + v^t_{si}\left(k - \frac{(N_k+1)}{2}\right)t_{exp}$$
$$y^t_{hijk} = FG_h\left(j - \frac{(N_j+1)}{2}\right)\frac{C_1 L_{si}}{N_j}\left|\cos\alpha_{hi}\right| \qquad \textbf{(EQ 9.12)}$$

where

- FG_{sd} is a parameter dependent on the satellite direction. It is defined so that $FG_{sd} = -1$ when the satellite is flying forward, and $FG_{sd} = 1$ when the satellite is flying backward.
- FG_h is a parameter dependent on the field of view. It is defined so that $FG_h = -1$ for field of view 1, and $FG_h = 1$ for field of view 2.
- L_{si} is the distance between any tangent point in the i^th row and the satellite given by

$$L_{si} = \sqrt{\left(Z^2_{satk_m} - (Z_{hij_mk_m} + R_{E_ih})^2\right)} \qquad \textbf{(EQ 9.13)}$$

- C_1 is the constant by which L_{si} must be multiplied to give the length of the arc in the atmosphere subtended by the bins in the i^{th} row.

$$C_1 = (N_j - 1) \bullet NHB \bullet DP \qquad \textbf{(EQ 9.14)}$$

- v^t_{si} - is the velocity of the tangent point volume associated with the satellite motion.

$$v^t_{si} = \frac{(Z_{hij_mk_m} + R_{E_ih})}{Z_{satk_m}} |V_{SAT}| \qquad \textbf{(EQ 9.15)}$$

- α_{hi} is the angle between the space craft velocity vector and the line of sight of the j^{th}_m column in the i^{th} row so that

$$\cos\alpha_{hi} = \frac{VECI_{hij_mk_m}(c) \bullet V_{SAT}}{|V_{SAT}|} \qquad \textbf{(EQ 9.16)}$$

and

$$\sin\alpha_{hi} = \sqrt{1 - \cos\alpha^2_{hi}} \qquad \textbf{(EQ 9.17)}$$

and

$$m_s = \frac{F_1 |\cos\alpha_{hi}\sin\alpha_{hi}|}{F_1 \sin^2\alpha_{hi} + F_2} \qquad \textbf{(EQ 9.18)}$$

where

$$F_1 = N_k \frac{C_1^2 L_{si}^2}{N_j^2} \sum_{j=1}^{N_j} \left(j - \frac{(N_j + 1)}{2}\right)^2 \qquad \textbf{(EQ 9.19)}$$

$$F_2 = v_{si}^{t2} t_s^2 \sum_{k=1}^{N_k} \left(k - \frac{(N_k+1)}{2} \right)^2 \qquad \textbf{(EQ 9.20)}$$

2. Calculate the co-ordinates of the intersection point $(x_{hijk}^{int}, y_{hijk}^{int})$, between the line of sight of each bin and the line L_M. In the co-ordinate system being used the slope of each line of sight, m_{hijk}, is

$$m_{hijk} = \frac{\sin\alpha_{hijk}}{\cos\alpha_{hijk}} \qquad \textbf{(EQ 9.21)}$$

where

$$\cos\alpha_{hijk} = \frac{VECI_{hijk}(c) \bullet V_{SAT}}{|V_{SAT}|} \qquad \textbf{(EQ 9.22)}$$

and

$$\sin\alpha_{hijk} = \sqrt{1 - \cos\alpha_{hijk}^2} \qquad \textbf{(EQ 9.23)}$$

The coordinates of the intesection point are

$$x_{hijk}^{int} = \frac{y_{hijk}^t - m_{hijk} x_{hijk}^t}{m_s - m_{hijk}} \qquad \textbf{(EQ 9.24)}$$

$$y_{hijk}^{int} = \frac{m_s (y_{hijk}^t - m_{hijk} x_{hijk}^t)}{m_s - m_{hijk}} \qquad \textbf{(EQ 9.25)}$$

3. The relative tangent point position x_{hijk} is the distance of these intesection points from the origin of co-ordinates.

$$x_{hijk} = \mathrm{sgn}\,(x_{hijk}^{int}) \sqrt{x_{hijk}^{int2} + y_{hijk}^{int2}} \qquad \textbf{(EQ 9.26)}$$

where sgn(x) is an operator giving the sign of x.

CHAPTER 10

A32 - Calculate apparent quantities

FUNCTIONAL DESCRIPTION:

The general expression for the intensity distribution at each bin, for the k^{th} step is

$$I_{hijk}^{T} = A\left(x_{hijk}\right)\left[\sum_{m} a_{hij}^{m} J1_{hij}^{m} + \sum_{m} b_{hijk}^{m} J2_{hij}^{m} - \sum_{m} c_{hijk}^{m} J3_{hij}^{m}\right] + I_{hi}^{B} \qquad \textbf{(EQ 10.1)}$$

where the various parameters are as defined in equation 8.46. **UPDATE** Of the 8 emission lines being considered here, four of them, the ${}^{P}Q(5)$, the ${}^{P}P(5)$, the ${}^{P}Q(7)$ and the ${}^{P}P(7)$ lines (indices m= 3, 4, 5, and 6) dominate the observed intensity distribution on the CCD. The remaining lines, the ${}^{P}Q(3)$, the ${}^{P}\mathrm{P}(3)$, the ${}^{P}Q(9)$ and the ${}^{P}P(9)$ lines (indices m= 1, 2, 7, and 8), in general contribute less than 5 % to the intensity observed at any bin. Thus their intensity can be in error by ±20 % (resulting in a net intensity error of 1 %) without unduly affecting the intensity estimation of the four stronger lines. For the purposes of this algorithm the variables associated with these lines will not be solved for but instead will be estimated, and their contribution to the image intensity calculated directly. This will be accomplished by determining their intensity as a portion of the ${}^{P}P(5)$ line for the ${}^{P}Q(3)$ and the ${}^{P}P(3)$ lines, and the ${}^{P}P(7)$ for the ${}^{P}Q(9)$ and the ${}^{P}P(9)$ lines. The proportionality constants will be provided in the CDB as functions of height and latitude. With this assumption we may write

$$I_{hijk}^{T} = A\left(x_{hijk}\right)\left[\sum_{w=1}^{4} \tilde{a}_{hij}^{w} J1_{hij}^{w+2} + \sum_{w=1}^{4} \tilde{b}_{hijk}^{w} J2_{hij}^{w+2} - \sum_{w=1}^{4} \tilde{c}_{hijk}^{w} J3_{hij}^{w+2}\right] + I_{hi}^{B} \qquad \textbf{(EQ 10.2)}$$

where

$$\tilde{a}^{2}_{hij} = I^{1}_{rathi} a^{1}_{hij} + I^{2}_{rathi} a^{2}_{hij} + a^{4}_{hij} \qquad \textbf{(EQ 10.3)}$$

$$\tilde{b}^{2}_{hijk} = I^{1}_{rathi} b^{1}_{hijk} + I^{2}_{rathi} b^{2}_{hijk} + b^{4}_{hijk} \qquad \textbf{(EQ 10.4)}$$

$$\tilde{c}^{2}_{hijk} = I^{1}_{rathi} c^{1}_{hijk} + I^{2}_{rathi} c^{2}_{hijk} + c^{4}_{hijk} \qquad \textbf{(EQ 10.5)}$$

$$\tilde{a}^{4}_{hij} = I^{7}_{rathi} a^{7}_{hij} + I^{8}_{rathi} a^{8}_{hij} + a^{6}_{hij} \qquad \textbf{(EQ 10.6)}$$

$$\tilde{b}^{4}_{hijk} = I^{7}_{rathi} b^{7}_{hijk} + I^{8}_{rathi} b^{8}_{hijk} + b^{6}_{hijk} \qquad \textbf{(EQ 10.7)}$$

$$\tilde{c}^{4}_{hijk} = I^{7}_{rathi} c^{7}_{hijk} + I^{8}_{rathi} c^{8}_{hijk} + c^{6}_{hijk} \qquad \textbf{(EQ 10.8)}$$

and

$$\{\tilde{a}^{1}_{hij}, \tilde{b}^{1}_{hijk}, \tilde{c}^{1}_{hijk}\} = \{a^{3}_{hij}, b^{3}_{hijk}, c^{3}_{hijk}\} \qquad \textbf{(EQ 10.9)}$$

$$\{\tilde{a}^{3}_{hij}, \tilde{b}^{3}_{hijk}, \tilde{c}^{3}_{hijk}\} = \{a^{5}_{hij}, b^{5}_{hijk}, c^{5}_{hijk}\} \qquad \textbf{(EQ 10.10)}$$

Here $I^{m}_{rathi} = I^{m}_{rat}(Z_{hi}, D_{N}, \vartheta R_{h})$ is the emission intensity ratio as calculated in A24432 from constants provided in the CDB.

The index ϖ has been introduced here to distinguish between the index m (1,2,...,8) being used to label the emissions in the band, and the index needed for summations over a subset of these lines, in general (1, 2,...,4).

The general procedure for solving for the unknowns, the JN^{m}_{hij}, m=3, 4, , 6, in this expression is to consider each of the intensity measurements in a given row in a particular field of view as providing information on these unknowns, and using the Multiple Linear Regression (MLR) algorithm to invert the intensity measurements to obtain the unknowns. We consider this formulation to be the baseline formulation for this algorithm.

In addition to this formulation there are two further variations which must be considered. These are considered in more detail below and their implementation is determined by a switch SW^{A} found in the CDB. SW^{A} is assigned values 1 to 4 depending on the option used. The options are:

Variation 1

The background may be included or excluded as an unknown to be solved for. Because the filter used for O_2 is very much narrower than the other filters used on WINDII the background contribution may be minimal, especially at night. In this case it may not be necessary to include I^B_{hi} as an unknown.

Variation 2

The form of the assumed variation of the intensity with relative tangent point position, $A(x_{hijk})$, may vary. The two possibilities being considered are a completely homogeneous atmosphere, in which case $A=1$ or a linear intensity variation in which case $A = (1 + \alpha_{hi} x_{hijk})$ and one must solve for the additional unknowns

$$\alpha_{hi} J^m_{hi}, \alpha_{hi} J2^m_{hi}, \alpha_{hi} J3^m_{hi} \qquad \textbf{(EQ 10.11)}$$

associated with the corresponding weighting functions

$$x_{hijk} \tilde{a}^w_{hij}, x_{hijk} \tilde{b}^w_{hijk} \; x_{hijk} \tilde{c}^w_{hijk} \qquad \textbf{(EQ 10.12)}$$

In each of these cases, the matrix equation has the form

$$\mathbf{I}_{hi} = \mathbf{R}_{hi} \mathbf{J}_{hi} \qquad \textbf{(EQ 10.13)}$$

with the specific form of $\mathbf{R}_{hi}$ and $\mathbf{J}_{hi}$ in depending on the particular variation implemented.

It is likely that the intensity measurements may be contaminated by intensity spikes due either to noise or stars. In order to correct for such an occurence a three step procedure is implemented in the solution for the line of sight quantities. This involves first solving for $\mathbf{J}_{hi}$ directly and then using this estimation to calculate an estimate for the input intensities. Comparison between this estimate and the input data for outliers provides a means for testing for spikes. The outliers are excluded in a second estimation of the $\mathbf{J}_{hi}$.

INPUT:

The input parameters are:

- SW^A - a switch determining which option should be used in the inversion to obtain the apparent quantities. It is aperture dependent and is assigned values '1' if no background and no intensity variation is assumed, '2' if a background but no intensity variation is assumed, '3' if no background but an intensity variation is assumed, '4' if a background and an intensity variation is assumed,
- DCA_{hijk} - the dark current map corresponding to the time of the measurement image adjusted for the dark current monitor (from A2112).
- x_{hijk} - the relative tangent point position for each bin in the measurement.
- a^m_{hij} - the weighting factor for each bin in the measurement window for the apparent quantities $J1^m_{hi}$.

- b^m_{hijk} - the weighting factor for each bin in the measurement window for the apparent quantities $J2^m_{hi}$.
- c^m_{hijk} - the weighting factor for each bin in the measurement window for the apparent quantities $J3^m_{hi}$.
- $I_{R_{hijk}}$ - corrected intensity data from A22.
- $I^m_{rat}(Z, D_N, \vartheta)$ - the ratio of the intensity of the ${}^PQ(3)$, ${}^PP(3)$, ${}^PQ(5)$,and ${}^PP(5)$ lines to the ${}^PP(5)$ line and the ratio of the intensity of the ${}^PQ(7)$, ${}^PP(9)$, ${}^PQ(9)$ and ${}^PP(7)$ lines to the ${}^PP(7)$ line. These ratios are calculated using A24432.
- QL_M - is a parameter (from the CDB) determining what deviation is to be considered an outlier.

OUTPUT:

The output parameters are:

- JN^m_{hi} - the apparent quantities associated with the line of sight for the hi^{th} row. Here $N = 1,2,3$, and $m = 3,4,5,6$.
- I^B_{hi} - the line of sight background for the hi^{th} row.
- $\sigma_{JN^m_{hi}}$ - error estimates for the JN^m_{hi} values.
- $\sigma_{I^B_{hi}}$ -error estimate for I^B_{hi}.

HYPOTHESIS OF APPLICABILITY:

This algorithm assumes that the variations in atmospheric quantities over the measurement are small enough that the solutions remain in the linear regime so that the derived line of sight quantities are averages of the corresponding instantaneous quantities. Furthermore, the approximations involved in the derivation of the weighting factors are assumed to introduce minimal errors in the derived apparent quantities.

CRITERIA OF APPLICABILITY:

To be applied to all O_2 measurements.

TRANSFORMATION EQUATIONS:

For this algorithm the Multiple Linear Regression (MLR) algorithm as written and used in the "WINDII Algorithm Description" is to be called whenever an inversion to obtain apparent quantities is needed. It is assumed that this algorithm is adequately described in that document and there is no need to describe this algorithm here. Furthermore it may be assumed that this algorithm is being referred to whenever "MLR" is used in the following paragraphs.

As noted above, the form of the matrix equation which must be solved using the MLR is

$$\mathbf{I}_{hi} = \mathbf{R}_{hi}\mathbf{J}_{hi} \tag{EQ 10.14}$$

where $\mathbf{I}_{\mathrm{hi}}$ is a column matrix, whose elements are the corrected intensity measurements. The ordering of these elements is

$$I_{his} = I_{R_h ijk} \tag{EQ 10.15}$$

$$s = (j-1) \times N_k + k \tag{EQ 10.16}$$

unless a bad bin occurs. In this case this element will be left out and the numbering adjusted accordingly.

$\mathbf{R}_{hi}(p,q)$ is the matrix of coefficients formed from the instrument weighting factors and $\mathbf{J}_{hi}(q)$ is a column matrix of the apparent quantities associated with the line of sight. The elements of both of these quantities depend on which variation (described above) is used. The variation to be used is controlled by SW^A which is in the CDB.

The form of these quantities is as follows, where account must be taken of bad bins in the same manner as above, where the $\tilde{a}^w_{hij}$, $\tilde{b}^w_{hijk}$ and $\tilde{c}^w_{hijk}$ are as defined above in equations 10.3 to 10.10,

Background not included, no intensity variation, $SW^A = 1$

$$J_{hi}(q) = J1^{w+2}_{hi}, q = (\varpi - 1) \bullet 3 + 1 \tag{EQ 10.17}$$

$$= J2^{w+2}_{hi}, q = (\varpi - 1) \bullet 3 + 2 \tag{EQ 10.18}$$

$$= J3^{w+2}_{hi}, q = (\varpi - 1) \bullet 3 + 3 \tag{EQ 10.19}$$

$$R_{hi}(q) = \tilde{a}^w_{hij}, p = s, q = (\varpi - 1) \bullet 3 + 1 \tag{EQ 10.20}$$

$$= \tilde{b}^w_{hijk}, p = s, q = (\varpi - 1) \bullet 3 + 2 \tag{EQ 10.21}$$

$$= -\tilde{c}^w_{hijk}, p = s, q = (\varpi - 1) \bullet 3 + 3 \tag{EQ 10.22}$$

Background included, no intensity variation, $SW^A = 2$

$$J_{hi}(q) = I^B_{hi}, p \quad 1 \tag{EQ 10.23}$$

$$= J1^{w+2}_{hi}, q = (\varpi - 1) \bullet 3 + 2 \tag{EQ 10.24}$$

$$= J2^{w+2}_{hi}, q = (\varpi - 1) \bullet 3 + 3 \tag{EQ 10.25}$$

$$= J3^{w+2}_{hi}, q = (\varpi - 1) \bullet 3 + 4 \tag{EQ 10.26}$$

$$\boldsymbol{R}_{hi}(q) = 1, q = 1, \text{all } p \tag{EQ 10.27}$$

$$= \tilde{a}^{w}_{hij}, p = s, q = (\varpi - 1) \bullet 3 + 2 \tag{EQ 10.28}$$

$$= \tilde{b}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 3 + 3 \tag{EQ 10.29}$$

$$= -\tilde{c}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 3 + 4 \tag{EQ 10.30}$$

Background not included, intensity variation included, $SW^{A} = 3$

$$\boldsymbol{J}_{hi}(q) = J1^{w+2}_{hi}, q = (\varpi - 1) \bullet 6 + 1 \tag{EQ 10.31}$$

$$= J2^{w+2}_{hi}, q = (\varpi - 1) \bullet 6 + 2 \tag{EQ 10.32}$$

$$= J3^{w+2}_{hi}, q = (\varpi - 1) \bullet 6 + 3 \tag{EQ 10.33}$$

$$= \alpha_{hi} J1^{w+2}_{hi}, q = (\varpi - 1) \bullet 6 + 4 \tag{EQ 10.34}$$

$$= \alpha_{hi} J2^{w+2}_{hi}, q = (\varpi - 1) \bullet 6 + 5 \tag{EQ 10.35}$$

$$= \alpha_{hi} J3^{w+2}_{hi}, q = (\varpi - 1) \bullet 6 + 6 \tag{EQ 10.36}$$

$$\boldsymbol{R}_{hi}(q) = \tilde{a}^{w}_{hij}, p = s, q = (\varpi - 1) \bullet 6 + 1 \tag{EQ 10.37}$$

$$= \tilde{b}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 6 + 2 \tag{EQ 10.38}$$

$$= -\tilde{c}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 6 + 3 \tag{EQ 10.39}$$

$$= x_{hijk} \tilde{a}^{w}_{hij}, p = s, q = (\varpi - 1) \bullet 6 + 4 \tag{EQ 10.40}$$

$$= x_{hijk} \tilde{b}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 6 + 5 \tag{EQ 10.41}$$

$$= -x_{hijk} \tilde{c}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 6 + 6 \tag{EQ 10.42}$$

Background included, intensity variation included, $SW^{A} = 4$

$$\boldsymbol{J}_{hi}(q) = I^{B}_{hi}, p = 1 \tag{EQ 10.43}$$

$$= J1_{hi}^{w+2}, q = (\varpi - 1) \bullet 6 + 2 \qquad \text{(EQ 10.44)}$$

$$= J2_{hi}^{w+2}, q = (\varpi - 1) \bullet 6 + 3 \qquad \text{(EQ 10.45)}$$

$$= J3_{hi}^{w+2}, q = (\varpi - 1) \bullet 6 + 4 \qquad \text{(EQ 10.46)}$$

$$= \alpha_{hi} J1_{hi}^{w+2}, q = (\varpi - 1) \bullet 6 + 5 \qquad \text{(EQ 10.47)}$$

$$= \alpha_{hi} J2_{hi}^{w+2}, q = (\varpi - 1) \bullet 6 + 6 \qquad \text{(EQ 10.48)}$$

$$= \alpha_{hi} J3_{hi}^{w+2}, q = (\varpi - 1) \bullet 6 + 7 \qquad \text{(EQ 10.49)}$$

$$\boldsymbol{R}_{hi}(q) = 1, q = 1, \text{all } p \qquad \text{(EQ 10.50)}$$

$$= \tilde{a}^{w}_{hij}, p = s, q = (\varpi - 1) \bullet 6 + 2 \qquad \text{(EQ 10.51)}$$

$$= \tilde{b}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 6 + 3 \qquad \text{(EQ 10.52)}$$

$$= -\tilde{c}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 6 + 4 \qquad \text{(EQ 10.53)}$$

$$= x_{hijk}\tilde{a}^{w}_{hij}, p = s, q = (\varpi - 1) \bullet 6 + 5 \qquad \text{(EQ 10.54)}$$

$$= x_{hijk}\tilde{b}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 6 + 6 \qquad \text{(EQ 10.55)}$$

$$= -x_{hijk}\tilde{c}^{w}_{hijk}, p = s, q = (\varpi - 1) \bullet 6 + 7 \qquad \text{(EQ 10.56)}$$

where $\varpi = 1, 2, \ldots, 4$ and the subscripts, j and k in the parameters above correspond to the j and k used to calculate s.

For the $\mathbf{I}_{hi}$, $\mathbf{R}_{hi}$ and $\mathbf{J}_{hi}$ defined according to the variation determined by the CDB flags the following steps are followed.

1. Solve for $\mathbf{J}_{hi}$ using all the data, excluding bins with bad bin flags. Denote this solution as $\boldsymbol{J}_{E^1_{hi}}$

2. Calculate the estimated intensities using

$$\boldsymbol{I}_{E_{hi}} = \boldsymbol{R}_{hi}\boldsymbol{J}_{E^1_{hi}} \qquad \text{(EQ 10.57)}$$

and compare $\boldsymbol{I}_{E_{hi}}$ to $\boldsymbol{I}_{hi}$ to search for outliers. Outliers are defined as being data points for which the difference between the estimated and actual intensities is greater than $QL_M\sigma_{I_{Ehijk}}$ where $\sigma_{I_{Ehijk}}$ is the estimated standard deviation expected from the estimated intensity. This is given by

$$\sigma_{I_{ehijk}} = \sqrt{I_{Ehijk} + DCA_{hijk}} \qquad \textbf{(EQ 10.58)}$$

These outliers are flagged and if the number of outliers is greater than a proportion Pout (provided in the CDB) of the total number of intensity samples in the row in the measurement then the measurement is flagged and no inversion for apparent quantities attempted.

3. Solve for $\mathbf{J}_{hi}$ again using all data, excluding bins with bad bin flags and bins associated with outliers.

The error estimates on the derived quantities are obtained from the MLR routine.

CHAPTER 11

A33 - Deconvolution to obtain height profiles

FUNCTIONAL DESCRIPTION:

The apparent quantities determined in algorithm A32 permit an estimate of the atmospheric profiles of temperature wind and number density of the excited state of O_2 to be made. This is accomplished by deconvolving these estimates to provide the profiles of the atmospheric quantities of interest. If self absorption is insignificant then deconvolution will proceed as with other emissions. If it is significant in the lower part of the window then the deconvolution will have to be modified. The first version of this algorithm in this case might be to perform inversions as currently is being done down to a given height (a parameter to be provided in the CDB) the inversion being know to be inaccurate below this height.

Final form of this algorithm is still TBD.

INPUT:

The input parameters are:

- JN_{hi}^{m} - the apparent quantities associated with the line of sight for the hi^{th} row. Here $N = 1, 2, 3$, and $m = 3, 4, 5, 6$.

- I_{hi}^{B} - the line of sight background for the hi^{th} row.
- $\sigma_{JN_{hi}^{m}}$ - error estimates for the JN_{hi}^{m} values.
- $\sigma_{I_{hi}^{B}}$ - error estimate for I_{hi}^{B}.

OUTPUT:

HYPOTHESIS OF APPLICABILITY:

CRITERIA OF APPLICABILITY:

TRANSFORMATION EQUATIONS:

CHAPTER 12

A34 - Derive atmospheric quantities

This algorithm consists of several functions. The derivation of the band volume emission rates is still to be determined. The derivation of the winds will be similar to the algorithms being used for other emissions. The derivation of rotational temperatures is likely to be similar to that used for OH, but the exact from is still to be determined.

Part IV

A4 - Production of UARS gridded data

To be accomplished as with the other emissions.

Chapter 12

A34 - Derive atmospheric quantities

This algorithm consists of three functions. The algorithm for the derivation of the wind for each of the O_2 emission lines is the same as the one being used for other emissions. The final wind profile is calculated at each height as a weighted average of the wind profiles for each emission line. The derivation of rotational temperatures is accomplished through a linear regression analysis of the inverted volume emission rates for each of the O_2 lines. The band volume emission rate is calculated as a function of the temperature and sum of the volume emission rates of each of the O_2 lines.

12.1 A341: Compute reference altitude profile

As in A331 of the same name in the WINDII algorithm document.

12.2 A342: Transform phase to wind

FUNCTIONAL DESCRIPTION: The inverted phase profile due to the atmospheric wind associated with each of the O_2 winds is converted to wind speed using the same approach as in A332: Transform Wind to Phase from the WINDII Algorithm Document. The final wind profile is then calculated as a weighted average of these profiles.

INPUT: The input parameters are:

- $\Delta^c_{\lambda_m}$ - Corrected OPD (in μm) for each line (from CDB).
- ϕ^m_{hi} - wind phase for each line for the given bin (from A33).
- $\sigma^m_{\phi_{hi}}$ - Estimate of the associated standard deviation in wind phase (from A33).
- λ_m - the emission wavelengths associated with the wind profiles (m=3,4,5,6) (from CDB).
- wf^w_m - Weighting factors to determine the relative weighting of the winds from the various lines in the determination of a final wind profile (from CDB).

OUTPUT: The output parameters are:

- w_{hi} - Wind speed (in m/s).
- $\sigma_{w_{hi}}$ - Estimate of the standard deviation in wind.

HYPOTHESIS OF APPLICABILITY: Assumes that the phase input to this subroutine is associated with the atmospheric wind only. The error in phase is the dominant error source.

CRITERIA OF APPLICABILITY: to be applied to all O2 Doppler measurements.

TRANSFORMATION EQUATIONS: The following steps are taken in deriving the wind:

1. For each of the four emission lines apply A32 - Transform Phase to Wind from the WINDII Algorithm Document to obtain winds w_{hi}^{m}.
2. Calculate the final output wind as a weighted average of the w_{hi}^{m} as follows:

$$w_{hi} = \frac{\sum_{m=3}^{6} \frac{wf_m^w}{\sigma_{\phi_{hi}}^{m\,2}} w_{hi}^{m}}{\sum_{m=3}^{6} \frac{wf_m^w}{\sigma_{\phi_{hi}}^{m\,2}}} \tag{12.1}$$

3. Calculate the associated standard deviation as the weighted average sigma given as

$$\sigma_{w_{hi}} = \sqrt{\frac{\left[\sum_{m=3}^{6} \frac{wf_m^{w\,2}}{(\sigma_{\phi_{hi}}^{m})^2}\right]}{\left[\sum_{m=3}^{6} \frac{wf_m^w}{(\sigma_{\phi_{hi}}^{m})^2}\right]^2}} \tag{12.2}$$

12.3 A342 Determine Rotational Temperature

FUNCTIONAL DESCRIPTION: The O_2 rotational temperature is accomplished by performing a linear regression analysis on a function of the volume emission rates for the four lines at a given altitude. The analysis is the classical one where the equation to fit is

$$\ln\left(\frac{E_{hi}^{m}}{S_m}\right) = C_1 + \frac{C_2^m}{T} \tag{12.3}$$

and E_{hi}^{m} is the volume emission rate of line m, T is the temperature in Kelvin, and S_m, and C_2^m are constants provided in the CDB. Linear regression analysis, including the error estimates is used to determine T. C_1 is not calculated since it is not used to derive any quantities of geophysical interest.

INPUT: The input parameters are:

- E_{hi}^{m} - the volume emission rate associated with each O_2 line (from A33).
- $\sigma_{E_{hi}}^{m}$ - the standard deviation associated with the emission (from A33).
- S_m - A vector of constants associated with the line strength factor for each line (provided in the CDB)
- C_2^m - A constant associated with the rotational constant for the transition, the rotational quantum numbers associated with the transition producing each line and the fundamental constants: Plancks constant, Boltzmann's constant and the speed of light.
- wf_T^m - A vector of weighting factors provided in the CDB providing the weights for each of the equations. These factors are determined experimentally through the validation process (to be provided in the CDB).

OUTPUT: The output parameters are:

- T_{hi} - the rotational temperature in Kelvin
- $\sigma_{T\,hi}$ - the error associated with T.

<u>HYPOTHESIS OF APPLICABILITY</u>: It is assumed that the input volume emission rate profiles have been appropriately corrected for background and that absorption effects are minimal.

<u>CRITERIA OF APPLICABILITY</u>: To be applied to all O_2 measurements.

<u>TRANSFORMATION EQUATIONS</u>: The equation

$$\ln(\frac{E^m_{hi}}{S_m}) = C_1 + \frac{C^m_2}{T} \tag{12.4}$$

is used as the basis of a linear regression analysis to determine the reciprocal of the temperature, T. Each equation is weighted by wf^m_T. The error on T, is that derived from the fit. This approach is based on the presentation in Numerical Recipes by Press et al.

The algorithm proceeds as follows. For each row:

1. Calculate the weights $wf^m_{R\,hi}$ for each equation to be used for the regression analysis based on the $\sigma^m_{E_{hi}}$ and the input weights wf^m_T.

$$wf^m_{R\,hi} = \frac{S_m}{wf^m_T\ E^m_{hi}}\sigma^m_{E_{hi}} \tag{12.5}$$

2. Calculate interim sums to be used in the calculations.

$$S1_{hi} = \sum_{m=3}^{6} \frac{1}{wf^m_{R\,hi}} \tag{12.6}$$

$$S2_{hi} = \sum_{m=3}^{6} \frac{C^m_2}{wf^m_{R\,hi}} \tag{12.7}$$

$$ST^m_{hi} = \frac{1}{wf^m_{R\,hi}}\left(C^m_2 - \frac{S2_{hi}}{S1_{hi}}\right) \tag{12.8}$$

$$ST2_{hi} = \sum_{m=3}^{6} (ST^m_{hi})^2 \tag{12.9}$$

3. Calculate T_{hi} and $\sigma_{T\,hi}$.

$$T_{hi} = \left[\frac{1}{ST2_{hi}} \sum_{m=3}^{6} \frac{ST_{hi}^{m} E_{hi}^{m}}{S_m \, w f_{R\,hi}^{m}} \right]^{-1} \qquad (12.10)$$

$$\sigma_{T\,hi} = \sqrt{\frac{T_{hi}^{2}}{ST2_{hi}}} \qquad (12.11)$$

12.4 A344 Calculation of the Band Volume Emission Rate

FUNCTIONAL DESCRIPTION: The band volume emission rate is calculated as a function of the intensities of each of the lines and the temperature. It is assumed that the intensities of the four lines observed represent a certain proportion of the band intensity. The proportion of the net intensity which they represent is a function of temperature. Here we assume that this proportion can be represented as a quadratic function of the temperature for the temperature range to be encountered in the atmosphere.

INPUT: The input parameters are:

- E_{hi}^{m} - the volume emission rate associated with each O_2 line.
- T_{hi} - the rotational temperature in Kelvin
- $\sigma_{E_{hi}}^{m}$ - the standard deviation associated with the emission.
- C_T^{p} - coefficients of the quadratic expression of temperature giving the proportion of the band intensity associated with these four lines. p=1, 2, 3.
- S_m - A vector of constants associated with the line strength factor for each line (provided in the CDB)

- C_2^m - A constant associated with the rotational constant for the transition, the rotational quantum numbers associated with the transition producing each line and the fundamental constants: Plancks constan, Boltzmann's constant and the speed of light.

- wf_T^m - A vector of weighting factors provided in the CDB providing corrections to the intensities. These factors are determined experimentally through the validation process (to be provided in the CDB).

OUTPUT: The output parameters are:

- E_{hi} - the band volume emission rate.

- $\sigma_{E_{hi}}$ - the error associated with the band volume emission rate.

HYPOTHESIS OF APPLICABILITY: It is assumed that the input intensities are unaffected by background and absorption. It is also assumed that the proportionality factor may be estimated accurately enough as a quadratic function of temperature.

CRITERIA OF APPLICABILITY: To be applied to all O_2 measurements.

TRANSFORMATION EQUATIONS: The band volume emission rate is given by

$$E_{hi} = \frac{\sum_{m=3}^{6} E_{hi}^m}{f(T)} \tag{12.12}$$

The error is given as

$$\sigma_{E_{hi}} = \sqrt{\left[\frac{\sum_{m=3}^{6} \sigma_{E_{hi}}^m}{(f(T))}\right]^2 + \left[\frac{(\sum_{n=3}^{6} E_{hi}^n)(C_T^2 + 2C_T^3\, T)\, T^2}{(f(T))^2\, ST2_{hi}}\right]^2 \left[\sum_{m=3}^{6} \frac{ST_{hi}^m}{S_m}\right]^2} \tag{12.13}$$

where

$$
\begin{aligned}
f(T) &= C_T^1 + C_T^2 T + C_T^3 T^2 & (12.14)\\
wf_{R\,hi}^m &= \frac{S_m}{wf_T^m\, E_{hi}^m}\sigma_{E_{hi}}^m & (12.15)\\
S1_{hi} &= \sum_{m=3}^{6} \frac{1}{wf_{R\,hi}^m} & (12.16)\\
S2_{hi} &= \sum_{m=3}^{6} \frac{C_2^m}{wf_{R\,hi}^m} & (12.17)\\
ST_{hi}^m &= \frac{1}{wf_{R\,hi}^m}\left(C_2^m - \frac{S2_{hi}}{S1_{hi}}\right) & (12.18)\\
ST2_{hi} &= \sum_{m=3}^{6} (ST_{hi}^m)^2. & (12.19)
\end{aligned}
$$

The latter 5 expressions are the same as those derived in A344.

12.5 A345 Flagging Data Affected by Absorption

FUNCTIONAL DESCRIPTION: Data below a height Ht_f may be affected by absorption and hence the simple inversion process used here prove incorrect. Hence data below this height will be flagged. This is accomplished in this subroutine.

INPUT:

OUTPUT:

HYPOTHESIS OF APPLICABILITY:

CRITERIA OF APPLICABILITY:

TRANSFORMATION EQUATIONS:

A final function includes flagging data considered to be affected by absorption. All data below Ht_F are flagged.

Memorandum

From: William Ward

To: Patrick Charlot

Copy: Brian Solheim, Yves Rochon

Subject: Changes to the O2 Algorithm Document

Date: June 9, 1994

The changes to the O2 Algorithm Document are as follows:

1. Change number on 'Determine Rotational Temperature' section to A343 from A342.
2. In equations 12.5 in section A343 and 12.15 in section A344, add a square root over wf_T^m.
3. In equations 12.6 and 12.7 in A343 and equations 12.16 and 12.17 in A344 square the denominator.
4. In equation 12.10 replace E_{hi}^m/S_m with $\ln(E_{hi}^m/S_m)$.
5. In equation 12.11, the square root should only include the denominator.
6. In equation 12.13, the expression has been revised to correct for an error.

12.2 A342: Transform phase to wind

FUNCTIONAL DESCRIPTION: The inverted phase profile due to the atmospheric wind associated with each of the O_2 winds is converted to wind speed using the same approach as in A332: Transform Wind to Phase from the WINDII Algorithm Document. The final wind profile is then calculated as a weighted average of these profiles.

INPUT: The input parameters are:

- $\Delta^c_{\lambda_m}$ - Corrected OPD (in μm) for each line (from CDB).
- ϕ^m_{hi} - wind phase for each line for the given bin (from A33).
- $\sigma^m_{\phi_{hi}}$ - Estimate of the associated standard deviation in wind phase (from A33).
- λ_m - the emission wavelengths associated with the wind profiles (m=3,4,5,6) (from CDB).
- wf^w_m - Weighting factors to determine the relative weighting of the winds from the various lines in the determination of a final wind profile (from CDB).

OUTPUT: The output parameters are:

- w_{hi} - Wind speed (in m/s).
- $\sigma_{w_{hi}}$ - Estimate of the standard deviation in wind.

HYPOTHESIS OF APPLICABILITY: Assumes that the phase input to this subroutine is associated with the atmospheric wind only. The error in phase is the dominant error source.

CRITERIA OF APPLICABILITY: to be applied to all O2 Doppler measurements.

TRANSFORMATION EQUATIONS: The following steps are taken in deriving the wind:

1. For each of the four emission lines apply A32 - Transform Phase to Wind from the WINDII Algorithm Document to obtain winds w_{hi}^m.
2. Calculate the final output wind as a weighted average of the w_{hi}^m as follows:
$$w_{hi} = \frac{\sum_{m=3}^{6} \frac{wf_m^w}{\sigma_{\phi_{hi}}^{m\,2}} w_{hi}^m}{\sum_{m=3}^{6} \frac{wf_m^w}{\sigma_{\phi_{hi}}^{m\,2}}} \tag{12.1}$$
3. Calculate the associated standard deviation as the weighted average sigma given as
$$\sigma_{w_{hi}} = \sqrt{\frac{\left[\sum_{m=3}^{6} \frac{wf_m^{w\,2}}{(\sigma_{\phi_{hi}}^m)^2}\right]}{\left[\sum_{m=3}^{6} \frac{wf_m^w}{(\sigma_{\phi_{hi}}^m)^2}\right]^2}} \tag{12.2}$$

12.3 A343 Determine Rotational Temperature

FUNCTIONAL DESCRIPTION: The O_2 rotational temperature is accomplished by performing a linear regression analysis on a function of the volume emission rates for the four lines at a given altitude. The analysis is the classical one where the equation to fit is

$$\ln(\frac{E_{hi}^m}{S_m}) = C_1 + \frac{C_2^m}{T} \tag{12.3}$$

and E^m_{hi} is the volume emission rate of line m, T is the temperature in Kelvin, and S_m, and C^m_2 are constants provided in the CDB. Linear regression analysis, including the error estimates is used to determine T. C_1 is not calculated since it is not used to derive any quantities of geophysical interest.

INPUT: The input parameters are:

- E^m_{hi} - the volume emission rate associated with each O_2 line (from A33).
- $\sigma^m_{E_{hi}}$ - the standard deviation associated with the emission (from A33).
- S_m - A vector of constants associated with the line strength factor for each line (provided in the CDB)
- C^m_2 - A constant associated with the rotational constant for the transition, the rotational quantum numbers associated with the transition producing each line and the fundamental constants: Plancks constan, Boltzmann's constant and the speed of light.
- wf^m_T - A vector of weighting factors provided in the CDB providing the weights for each of the equations. These factors are determined experimentally through the validation process (to be provided in the CDB).

OUTPUT: The output parameters are:

- T_{hi} - the rotational temperature in Kelvin
- $\sigma_{T\,hi}$ - the error associated with T.

HYPOTHESIS OF APPLICABILITY: It is assumed that the input volume emission rate profiles have been appropriately corrected for background and that absorption effects are minimal.

CRITERIA OF APPLICABILITY: To be applied to all O_2 measurements.

TRANSFORMATION EQUATIONS: The equation

$$\ln(\frac{E_{hi}^m}{S_m}) = C_1 + \frac{C_2^m}{T} \tag{12.4}$$

is used as the basis of a linear regression analysis to determine the reciprocal of the temperature, T. Each equation is weighted by wf_T^m. The error on T, is that derived from the fit. This approach is based on the presentation in Numerical Recipes by Press et al.

The algorithm proceeds as follows. For each row:

1. Calculate the weights $wf_{R\,hi}^m$ for each equation to be used for the regression analysis based on the $\sigma_{E_{hi}}^m$ and the input weights wf_T^m.

$$wf_{R\,hi}^m = \frac{S_m}{\sqrt{wf_T^m\, E_{hi}^m}} \sigma_{E_{hi}}^m \tag{12.5}$$

2. Calculate interim sums to be used in the calculations.

$$\begin{aligned} S1_{hi} &= \sum_{m=3}^{6} \frac{1}{wf_{R\,hi}^{m\,2}} && (12.6) \\ S2_{hi} &= \sum_{m=3}^{6} \frac{C_2^m}{wf_{R\,hi}^{m\,2}} && (12.7) \\ ST_{hi}^m &= \frac{1}{wf_{R\,hi}^m}\left(C_2^m - \frac{S2_{hi}}{S1_{hi}}\right) && (12.8) \\ ST2_{hi} &= \sum_{m=3}^{6} (ST_{hi}^m)^2 && (12.9) \end{aligned}$$

3. Calculate T_{hi} and $\sigma_{T\,hi}$.

$$T_{hi} = \left[\frac{1}{ST2_{hi}}\sum_{m=3}^{6}\frac{ST_{hi}^{m}}{wf_{R\,hi}^{m}}\ln\left(\frac{E_{hi}^{m}}{S_m}\right)\right]^{-1} \tag{12.10}$$

$$\sigma_{T\,hi} = \frac{T_{hi}^{2}}{\sqrt{ST2_{hi}}} \tag{12.11}$$

12.4 A344 Calculation of the Band Volume Emission Rate

FUNCTIONAL DESCRIPTION: The band volume emission rate is calculated as a function of the intensities of each of the lines and the temperature. It is assumed that the intensities of the four lines observed represent a certain proportion of the band intensity. The proportion of the net intensity which they represent is a function of temperature. Here we assume that this proportion can be represented as a quadratic function of the temperature for the temperature range to be encountered in the atmosphere.

INPUT: The input parameters are:

- E_{hi}^{m} - the volume emission rate associated with each O_2 line.
- T_{hi} - the rotational temperature in Kelvin
- $\sigma_{E_{hi}}^{m}$ - the standard deviation associated with the emission.
- C_T^p - coefficients of the quadratic expression of temperature giving the proportion of the band intensity associated with these four lines. p=1, 2, 3.
- S_m - A vector of constants associated with the line strength factor for each line (provided in the CDB)

- C_2^m - A constant associated with the rotational constant for the transition, the rotational quantum numbers associated with the transition producing each line and the fundamental constants: Plancks constan, Boltzmann's constant and the speed of light.
- wf_T^m - A vector of weighting factors provided in the CDB providing corrections to the intensities. These factors are determined experimentally through the validation process (to be provided in the CDB).

OUTPUT: The output parameters are:

- E_{hi} - the band volume emission rate.
- $\sigma_{E_{hi}}$ - the error associated with the band volume emission rate.

HYPOTHESIS OF APPLICABILITY: It is assumed that the input intensities are unaffected by background and absorption. It is also assumed that the proportionality factor may be estimated accurately enough as a quadratic function of temperature.

CRITERIA OF APPLICABILITY: To be applied to all O_2 measurements.

TRANSFORMATION EQUATIONS: The band volume emission rate is given by

$$E_{hi} = \frac{\sum_{m=3}^{6} E_{hi}^m}{f(T)} \tag{12.12}$$

The error is given as

$$\sigma_{E_{hi}} = f(T)^{-1} \sqrt{\sum_{m=3}^{6} \left[\sigma_{E_{hi}}^m + E_{hi} \frac{(C_T^2 + 2C_T^3 T)}{ST2_{hi} T^2} ST_{hi}^m \sqrt{wf_T^m} \right]^2} \tag{12.13}$$

where

$$
\begin{aligned}
f(T) &= C_T^1 + C_T^2 T + C_T^3 T^2 && (12.14)\\
wf^m_{R\,hi} &= \frac{S_m}{\sqrt{wf^m_T \, E^m_{hi}}}\sigma^m_{E_{hi}} && (12.15)\\
S1_{hi} &= \sum_{m=3}^{6} \frac{1}{wf^{m\,2}_{R\,hi}} && (12.16)\\
S2_{hi} &= \sum_{m=3}^{6} \frac{C_2^m}{wf^{m\,2}_{R\,hi}} && (12.17)\\
ST^m_{hi} &= \frac{1}{wf^m_{R\,hi}}\left(C_2^m - \frac{S2_{hi}}{S1_{hi}}\right) && (12.18)\\
ST2_{hi} &= \sum_{m=3}^{6} (ST^m_{hi})^2. && (12.19)
\end{aligned}
$$

The latter 5 expressions are the same as those derived in A344.

12.5 A345 Flagging Data Affected by Absorption

FUNCTIONAL DESCRIPTION: Data below a height Ht_f may be affected by absorption and hence the simple inversion process used here prove incorrect. Hence data below this height will be flagged. This is accomplished in this subroutine.

INPUT:

OUTPUT:

HYPOTHESIS OF APPLICABILITY:

CRITERIA OF APPLICABILITY:

TRANSFORMATION EQUATIONS:

A final function includes flagging data considered to be affected by absorption. All data below Ht_F are flagged.

Chapter 11

A33 - Deconvolution to obtain height profiles

FUNCTIONAL DESCRIPTION: The apparent quantities determined in algorithm A32 permit an estimate of the atmospheric profiles of Doppler temperature wind and number density of the excited state of O_2 to be made. This is accomplished by deconvolving the apparent quantities to provide profiles of the atmospheric quantities of interest. The deconvolution is to proceed as with other simple lines (ie using algorithms A321, A322 and A323 in the WINDII algorithm document) except that data from each of the four emission lines will be inverted. If self absorption is significant in the lower part of the window then the height above which data is to be considered trustworthy will be provided as a parameter in the CDB and the data below this height flagged.

INPUT: The input parameters are:

- JN_{hi}^{m} - the apparent quantities associated with the line of sight for the hith row. Here $N = 1, 2, 3$, and $m = 3, 4, 5, 6$.

- $\sigma_{JN^m_{hi}}$ - error estimates for the JN^m_{hi} values.
- Ht_F - the height below which the simple inversion process described here is deemed to be invalid and hence the data in error.
- Other quantities defined in A32 - Deconvolution of Apparent Quantities in the WINDII Algorithm Document.

OUTPUT: The output parameters are:

- Output quantities as defined in A32 for each line (to be distinguished by the superscript m).

HYPOTHESIS OF APPLICABILITY: This assumes that the atmosphere is sufficiently uniform that these inversions are sensible.

CRITERIA OF APPLICABILITY: To be applied to all O_2 measurements.

TRANSFORMATION EQUATIONS: See Algorithm A32 - Deconvolution of Apparent Quantities in the WINDII Algorithm Document.

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September 15, 1994

Dear Patrick,

Attached are the changes to the O2 algorithm required to incorporate the one parameter fit. In implementing this I think that simply using a switch ie the parameter, FM_V, and duplicating the filter parameter code may be the best approach. The preliminary results of my analysis of the filter parameter determinations are inconclusive. I will be working further on it.

Yours sincerely,

William Ward

William Ward

Chapter 8

A244 - Determine filter parameters

NOTE: Two options have been identified for determining the filter parameters. In one option only the wavelength of the peak transmission at normal incidence λ_0 is determined, and in the other the wavelength of the peak transmission at normal incidence λ_0 and the effective refractive index μ_e are solved for. The option which is to be implemented in a particular run of the SDPPS is determined through the value of a parameter FM_V provided in the CDB. If FM_V=1 then a one parameter fit is performed and if FM_V=2 then a two parameter fit is performed. In this section and in section A2444 algorithms for both these options are provided in parallel whenever required.

FUNCTIONAL DESCRIPTION: Because it is possible that the filter parameters may drift with temperature and time (through aging) it is necessary to determine the filter parameters on orbit. There are three steps to this procedure. The first is to find suitable images from which the parameters may be derived. The criterion to be used is that the sums of images k and k+4, (k=1,..4) for an 8-point measurement, sums of images 1 and 3, 2 and 4, 5 and 7, and 6 and 8 for a double 4-point measurement or sums of images 1 and 3, and 2 and 4 for a 4-point measurement be compared to ensure the intensity variation during a measurement is minimal. When a set of images satisfying this criteria are found the filter parameters associated with each image are determined. The filter parameters to be used for the data analysis are then found by interpolation (at the present time presumed to be quadratic).

INPUT: The input parameters are listed below in the subsequent subsections.

OUTPUT: The output parameters are:

- $C_r^{\lambda_o A}$ - the coefficients of the quadradic expression giving the filter parameter λ_o as a function of universal time ($r = 1, \ldots, 3$). The coefficients are a function of aperture.

- If FM_V = 2 then $C_r^{\mu_e A}$ is also calculated. $C_r^{\mu_e A}$ - the coefficients of the quadradic expression giving the filter parameter μ_e as a function of universal time ($r = 1, \ldots, 3$). The coefficients are a function of aperture.

HYPOTHESIS OF APPLICABILITY: It is assumed that the filter function is described by the Lissberger formula

$$\tau(\lambda, \theta) = \frac{\tau_{max}(\theta)}{1 + \mid \left[\frac{2(\lambda - \lambda_o)}{(\Delta\lambda)_o} + \frac{\lambda_o}{(\Delta\lambda)_o} \frac{\theta^2}{\mu_e^2} \right] \mid^{fexp}}. \tag{8.1}$$

Here λ_o is the wavelength at peak transmittance at normal incidence through the filter, μ_e is an effective refractive index characterizing the dependence of transmittance with angle, $(\Delta\lambda)_o$ is the spectral half-width of the filter at normal incidence, fexp is an exponent controlling the filter shape, θ is the angle of incidence at the filter for the ray passing to a particular point on the CCD, λ is the wavelength for which the transmittance is being calculated where τ_{max} is the transmissivity as a function of the angle θ.

<u>CRITERIA OF APPLICABILITY</u>: This function is to be accomplished for a set of O_2 measurements in the day which meet specific stability criteria to be set forth below.

<u>TRANSFORMATION EQUATIONS</u>: The structure of this algorithm is as follows:

1. For the full day
   - (a) Perform A2442, starting at the first measurement until a suitable measurement is found.
   - (b) Perform A2443 on the suitable measurement to determine associated filter parameters.
   - (c) Increment the universal time by ΔT (from the CDB).
   - (d) Continue the cycle (a to c) starting with the next measurement after the new universal time.
2. With the filter parameters estimates from step 1, calculate a quadratic fit to the day and night values to retrieve $C_r^{\lambda_o A}$ and if FM_V=2, $C_r^{\mu_o A}$.

and calculate its mean, excluding bad bins from the calculation, $\overline{Rat}^W$ over i, j, and h.

IF $\overline{Rat}^W > \text{QL}$ **THEN** the measurement is considered unsuitable for filter parameter determinations.

8.3 A2443 - Calculate filter parameters

If FM_V=1,

<u>FUNCTIONAL DESCRIPTION</u>: The wavelength of the peak transmission at normal incidence $\lambda_\circ$ is determined for measurements not rejected. This estimation is accomplished by minimizing the root mean square (RMS) difference between the measured intensity values and the filter model (based on the Lissberger formula) using a nonlinear least mean squares approach for one dimension.

The quantities needed for the filter model are the Doppler shifted wavelengths of the emissions being observed, λ^m_{hij}, the angles through the filter corresponding to each pixel on the CCD, and the filter parameters, μ_e, the effective refractive index, $(\Delta\lambda)_\circ$, the filter half width at half height, and fexp, the exponent describing the shape of the filter function.

<u>INPUT</u>: The input parameters are:

- N_i - number of measurement bins or rows in the vertical.
- N_j - number of measurement bins or columns in the horizontal.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.

- **NVO - vertical offset of the measurement window from the bottom of the CCD in bins.**

- **NHO - horizontal offset of the measurement window from the outside edges of the CCD.**

- **NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.**

- **NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.**

- **θ_{hij}^{FpW} - the filter angles for each pixel in the reduced window (from A2441).**

- **$\overline{I_{hij}^{TW}}$ - the mean intensity image for the reduced window for the measurement being considered (from A24422).**

- **$Flags_{hij}^{W}$ - the bad bin flags for the reduced window for the mean intensity image $\overline{I_{hij}^{TW}}$ (from A24422).**

- **λ_o^e - An estimate of the wavelength of the peak transmission at normal incidence λ_o (from the CDB).**

- **μ_e^e - An estimate of the effective refractive index μ_e (from the CDB).**

- **$(\Delta\lambda)_o^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.**

- **$fexp^A$ - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.**

- λ_m, $m = 1, 2, ..., 8$ - the eight emission wavelengths contributing to the intensity measured with the O_2 filter (from CDB).

- vps_{hij}^{Wp} - projected spacecraft velocity along line of sight, for all pixels in the reduced window (from A2221).

- vre_{hij}^{Wp} - velocity of the earth rotation at the tangent point on a latitude circle for all pixels in the reduced window (from A2221).

- c - the speed of light ($= 2.99792459 \times 10^8$ m/s)(from CDB).

- $\tau(\theta)$ - the transmissivity of the filter as a function of the angle of incidence on the filter (provided as a function of three parameters in the CDB).

- $\vartheta_{R_h}^{W}$ - reference geodetic latitude of tangent point for the row of peak intensity in the reduced window for the measurement being considered (from $\vartheta_{R_{hi}}^{W}$ calculated in A221).

- Z_{hi} - the geodetic altitude for each row in the reduced window calculated at the middle image of each measurement and the column closest to the centre of each measurement window (from A221).

- D_N - the day number (number of days after January 1) of the measurement.

<u>OUTPUT</u>: The output parameters are:

- λ_o - The wavelength of the peak transmission at normal incidence of the filter.

- UT_4 - the universal time associated with the fourth image of the measurement.

HYPOTHESIS OF APPLICABILITY: For this algorithm it is assumed that interferometer effects can be eliminated by summing over N_k. This means that the deviation of the phase steps from $\pi/8$ (for $N_k = 8$) or $\pi/4$ (for $N_k = 4$) is negligable for the O_2 emissions being observed. Furthermore it is being assumed that the intensity variations across the CCD are attributable primarily to filter effects and that intensity variations due to the atmosphere are negligable either because these variations in fact are small, or because adjacent bins across a row view almost the same volume of air. Finally it is assumed that the intensity variation of the lines in the band being observed with WINDII do not vary greatly with temperature, so that atmospheric temperature variations will not dominate the intensity variations across the CCD.

CRITERIA OF APPLICABILITY: Applied to all suitable O_2 measurements as determined by A2442.

TRANSFORMATION EQUATIONS:

The steps in this algorithm are:

1. Calculate the emission intensities in each row in the FP window, A24431.
2. Calculate the Doppler shifted wavelengths for each pixel in this window A24433. The velocity fields used here may have to be interpolated to a pixel by pixel basis at this point depending on how the velocities are calculated in A2221.
3. Calculate the mean observed intensity for each FOV, A24434.

4. Find the filter parameter $\lambda_\circ$ which minimizes the least mean square difference between the observed intensities and the model in the FP window (A24435).

If FM_V=2,

FUNCTIONAL DESCRIPTION: The wavelength of the peak transmission at normal incidence $\lambda_\circ$ and the effective refractive index is determined for measurements not rejected. This estimation is accomplished by minimizing the root mean square (RMS) difference between the measured intensity values and the filter model (based on the Lissberger formula) using a nonlinear least mean squares approach for two dimensions.

The quantities needed for the filter model are the Doppler shifted wavelengths of the emissions being observed, λ^m_{hij}, the angles through the filter corresponding to each pixel on the CCD, and the filter parameters, $(\Delta\lambda)_\circ$, the filter half width at half height, and fexp, the exponent describing the shape of the filter function.

INPUT: The input parameters are:

- N_i - number of measurement bins or rows in the vertical.
- N_j - number of measurement bins or columns in the horizontal.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.
- NVO - vertical offset of the measurement window from the bottom of the CCD in bins.

- **NHO - horizontal offset of the measurement window from the outside edges of the CCD.**

- **NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.**

- **NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.**

- **θ_{hij}^{FpW} - the filter angles for each pixel in the reduced window (from A2441).**

- **$\overline{I_{hij}^{TW}}$ - the mean intensity image for the reduced window for the measurement being considered (from A24422).**

- **$Flags_{hij}^{W}$ - the bad bin flags for the reduced window for the mean intensity image $\overline{I_{hij}^{TW}}$ (from A24422).**

- **$\lambda_{\circ}^{e}$ - An estimate of the wavelength of the peak transmission at normal incidence $\lambda_{\circ}$ (from the CDB).**

- **μ_{e}^{e} - An estimate of the effective refractive index μ_{e} (from the CDB).**

- **$(\Delta\lambda)_{\circ}^{A}$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.**

- **fexp^{A} - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.**

- **λ_{m}, $m = 1, 2, ..., 8$ - the eight emission wavelengths contributing to the intensity measured with the O_2 filter (from CDB).**

- $\mathrm{vps}_{hij}^{W\,p}$ - projected spacecraft velocity along line of sight, for all pixels in the reduced window (from A2221).
- $\mathrm{vre}_{hij}^{W\,p}$ - velocity of the earth rotation at the tangent point on a latitude circle for all pixels in the reduced window (from A2221).
- c - the speed of light ($= 2.99792459 \times 10^8$ m/s)(from CDB).
- $\tau(\theta)$ - the transmissivity of the filter as a function of the angle of incidence on the filter (provided as a function of three parameters in the CDB).
- $\vartheta_{R_h}^{W}$ - reference geodetic latitude of tangent point for the row of peak intensity in the reduced window for the measurement being considered (from $\vartheta_{R_{hi}}^{W}$ calculated in A221).
- Z_{hi} - the geodetic altitude for each row in the reduced window calculated at the middle image of each measurement and the column closest to the centre of each measurement window (from A221).
- D_N - the day number (number of days after January 1) of the measurement.

OUTPUT: The output parameters are:

- λ_o - The wavelength of the peak transmission at normal incidence of the filter.
- μ_e The effective refractive index best characterizing the behaviour of the filter.

- UT_4 - the universal time associated with the fourth image of the measurement.

HYPOTHESIS OF APPLICABILITY: For this algorithm it is assumed that interferometer effects can be eliminated by summing over N_k. This means that the deviation of the phase steps from $\pi/8$ (for $N_k = 8$) or $\pi/4$ (for $N_k = 4$) is negligable for the O_2 emissions being observed. Furthermore it is being assumed that the intensity variations across the CCD are attributable primarily to filter effects and that intensity variations due to the atmosphere are negligable either because these variations in fact are small, or because adjacent bins across a row view almost the same volume of air. Finally it is assumed that the intensity variation of the lines in the band being observed with WINDII do not vary greatly with temperature, so that atmospheric temperature variations will not dominate the intensity variations across the CCD.

CRITERIA OF APPLICABILITY: Applied to all suitable O_2 measurements as determined by A2442.

TRANSFORMATION EQUATIONS:

The steps in this algorithm are:

1. Calculate the emission intensities in each row in the FP window, A24431.
2. Calculate the Doppler shifted wavelengths for each pixel in this window A24433. The velocity fields used here may have to be interpolated to a pixel by pixel basis at this point depending on how the velocities are calculated in A2221.
3. Calculate the mean observed intensity for each FOV, A24434.

4. Find the filter parameters λ_o and μ_e which minimize the least mean square difference between the observed intensities and the model in the FP window (A24435).

8.3.1 A24431: Calculation of the emission intensities in each row

FUNCTIONAL DESCRIPTION: To calculate the filter parameters the intensities of each of the contributing lines is needed. These intensities are calculated by determining the peak intensities in each of the rows being used in each half of each field of view. These intensities are attributed to the $^{P}P(5)$ and $^{P}P(7)$ lines. The remaining lines are calculated relative to these intensities using constants which are a function of height, latitude and day number.

INPUT: The input parameters are:

- $\overline{I^{T,W}_{hij}}$ - the mean intensity image for the bins in the reduced window for the measurement being considered (from A24422).
- $\vartheta^{W}_{R_h}$ - reference geodetic latitude of tangent point for the row of peak intensity in the reduced window for the measurement being considered (from $\vartheta^{W}_{R_{hi}}$ calculated in A221).
- Z^{W}_{hi} - the geodetic altitude for each row in the reduced window calculated at the middle image of each measurement and the column closest to the centre of each measurement window (from A221).
- D_N - the day number (number of days after January 1) of the measurement.

CRITERIA OF APPLICABILITY: For all calculations of the filter parameters.

TRANSFORMATION EQUATIONS:

Define $N^F_{R\,h}$ as the number of rows in each field of view in the FP window. The number of good bins in the reduced window is

$$NB_h = \sum_{i=1}^{N^F_{R\,h}} \sum_{j=1}^{N_j} Flags^W_{hij} \tag{8.42}$$

$$\overline{I^{T\,W}_{M\,h}} = \frac{1}{NB_h} \sum_{i=1}^{N^F_{R\,h}} \sum_{j=1}^{N_j} Flags^W_{hij} \overline{I^{T\,W}_{hij}} \tag{8.43}$$

8.3.5 A24435: Determine the filter parameters

If FM_V=1,

FUNCTIONAL DESCRIPTION: The filter parameter, λ_o, is determined by minimizing in a least mean squares sense the difference between the intensity field in the FP window and an estimate of the intensity for this window obtained using the Lissberger formula.

INPUT: The input parameters are:

- $\overline{I^{T\,W}_{hij}}$ - the mean intensity image for the measurement being considered (from A24422).
- $\overline{I^{T\,W}_{M\,h}}$ - the mean intensity for each field of view (from A24434).
- $Flags^W_{hij}$ - the bad bin flags for the reduced window for the mean intensity image $\overline{I^{T\,W}_{hij}}$ (from A24422).
- $\theta^{F\,p\,W}_{hij}$ - the filter angles for each pixel in the reduced window being used for filter parameter determination (from A2441).

- $\mathrm{IM}_{hi}^{m\,W}$ - the intensities of the emission lines for each row being used for filter parameter determination (from A24431).
- $\lambda_{hij}^{m\,p\,W}$, $m = 1, 2, ..., 8$ - the Doppler shifted wavelengths for each pixel in the window being used for the filter determination (from A24433).
- $\lambda_\circ^e$ - An estimate of the wavelength of the peak transmission at normal incidence $\lambda_\circ$ (from the CDB).
- μ_e^e - An estimate of the effective refractive index μ_e (from the CDB). It is a function of aperture.
- $(\Delta\lambda)_\circ^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- fexp^A - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT: The output parameter is:

- $\lambda_\circ^A(UT)$ - The wavelength of the peak transmission at normal incidence of the filter best characterizing the behaviour of the filter.
- UT - the universal time of the measurement.

HYPOTHESIS OF APPLICABILITY: The filter is assumed to be adequately described by the Lissberger formula.

CRITERIA OF APPLICABILITY: To be applied to all suitable O_2 measurements as determined in A2442.

TRANSFORMATION EQUATIONS: Determine $\lambda_\circ$ and μ_e by minimizing in a least mean squares sense, using standard techniques (ie the

NAG library), the merit function

$$MF = \sum_{hij} (\overline{I^{TW}_{hij}} - I^{FW}_{hij}(\lambda_\circ))^2 \qquad (8.44)$$

with respect to these parameters. The sum is only over good bins as determined by Flags_{hij}. $I^{FW}_{hij}(\lambda_\circ)$ is the modelled intensity due to the m emissions at the ijth bin after transmission through the filter. The evaluation of this function is described below in A244351. The starting value for this minimization is $\lambda^e_\circ$ given in the CDB.

If FM_V=2,

<u>FUNCTIONAL DESCRIPTION</u>: The filter parameters, $\lambda_\circ$ and μ_e, are determined by minimizing in a least mean squares sense the difference between the intensity field in the FP window and an estimate of the intensity for this window obtained using the Lissberger formula.

<u>INPUT</u>: The input parameters are:

- $\overline{I^{TW}_{hij}}$ - the mean intensity image for the measurement being considered (from A24422).
- $\overline{I^{TW}_{Mh}}$ - the mean intensity for each field of view (from A24434).
- $Flags^W_{hij}$ - the bad bin flags for the reduced window for the mean intensity image $\overline{I^{TW}_{hij}}$ (from A24422).
- θ^{FpW}_{hij} - the filter angles for each pixel in the reduced window being used for filter parameter determination (from A2441).
- IM^{mW}_{hi} - the intensities of the emission lines for each row being used for filter parameter determination (from A24431).

- λ_{hij}^{mpW}, $m = 1, 2, ..., 8$ - the Doppler shifted wavelengths for each pixel in the window being used for the filter determination (from A24433).

- $\lambda_\circ^e$ - An estimate of the wavelength of the peak transmission at normal incidence $\lambda_\circ$ (from the CDB).

- μ_e^e - An estimate of the effective refractive index μ_e (from the CDB).

- $(\Delta\lambda)_\circ^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.

- fexp^A - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT: The output parameters are:

- $\lambda_\circ^A(UT)$ - The wavelength of the peak transmission at normal incidence of the filter best characterizing the behaviour of the filter.

- $\mu_e^A(UT)$ The effective refractive index best characterizing the behaviour of the filter.

- UT - the universal time of the measurement.

HYPOTHESIS OF APPLICABILITY: The filter is assumed to be adequately described by the Lissberger formula.

CRITERIA OF APPLICABILITY: To be applied to all suitable O_2 measurements as determined in A2442.

TRANSFORMATION EQUATIONS: Determine $\lambda_\circ$ and μ_e by minimizing in a least mean squares sense, using standard techniques (ie the

NAG library), the merit function

$$MF = \sum_{hij} (\overline{I^{TW}_{hij}} - I^{FW}_{hij}(\lambda_o, \mu_e))^2 \tag{8.45}$$

with respect to these parameters. The sum is only over good bins as determined by Flags_{hij}. $I^{FW}_{hij}(\lambda_o, \mu_e)$ is the modelled intensity due to the m emissions at the ijth bin after transmission through the filter. The evaluation of this function is described below in A244351. The starting values for this minimization are λ_o^e and μ_e^e given in the CDB.

A244351 - Calculation of the net intensity after passage through the filter

If FM_V=1,

<u>FUNCTIONAL DESCRIPTION</u>: This routine calculates the intensity incident on the hijth bin of the CCD as determined by the effect of the filter (omitting the Michelson effects). In it the intensity is first calculated on a pixel by pixel basis and then binned according to the binning used in the image being analysed. The mean intensity over each window in each field of view, $\overline{I^{FW}_{Mh}}$, is then calculated and along with the mean intensity of the observed intensities, $\overline{I^{TW}_{Mh}}$, used to normalize the result.

<u>INPUT</u>: The input parameters are:

- $\overline{I^{TW}_{Mh}}$ - the mean intensity for each field of view (from A24434).
- θ^{FpW}_{hij} - the filter angles for each pixel in the reduced window being used for filter parameter determination (from A2441).
- IM^{mW}_{hi} - the intensities of the emission lines for each row being used for filter parameter determination (from A24431).

- λ_{hij}^{mpW}, $m = 1, 2, ..., 8$ - the Doppler shifted wavelengths for each pixel in the window being used for the filter determination.
- $\lambda_\circ$ - the wavelength at peak transmission at normal incidence, an input parameter.
- μ_e^e - the effective refractive index, an input parameter (from the CDB). It is a function of aperture.
- $(\Delta\lambda)_\circ^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- fexp^A - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT: The output parameters are:

- $I_{hij}^{FW}(\lambda_\circ)$ - the model intensity incident on the hijth bin due to the filter alone.

HYPOTHESIS OF APPLICABILITY: It is assumed that the Lissberger formula provides an accurate model of the behaviour of the O_2 filter on WINDII.

CRITERIA OF APPLICABILITY: To be used for all estimations of the filter parameters.

TRANSFORMATION EQUATIONS: The steps in this function are:

1. Calculate the intensity $I_{hij}^{FpmW}(\lambda_\circ)$ at the CCD for each pixel in the reduced window being used for filter parameter determination, using

$$I_{hij}^{FpmW}(\lambda_\circ) = IM_{hi}^{mW} \times \mathcal{F}(\lambda_\circ; \theta_{hij}^{FpW}, \lambda_{hij}^{mpW}, \mu_e^e, (\Delta\lambda)_\circ^A, fexp^A) \tag{8.46}$$

The evaluation of $\mathcal{F}$ is given in A244352.

2. Calculate the intensity due to each emission at each bin $I_{hij}^{F\,m\,W}(\lambda_\circ)$ by summing over the pixels contributing to each bin

$$I_{hij}^{F\,m\,W}(\lambda_\circ) = \sum_{pixels} I_{hij}^{F\,p\,m\,W}(\lambda_\circ) \tag{8.47}$$

3. Calculate the net intensity at each bin $I_{hij}^{F\,W\,*}(\lambda_\circ)$ by summing over the contributing emissions

$$I_{hij}^{F\,W\,*}(\lambda_\circ) = \sum_{m} I_{hij}^{F\,m\,W}(\lambda_\circ) \tag{8.48}$$

4. Calculate the mean intensity in each window of each field of view $\overline{I_{M\,h}^{F\,W}}$ from the model data using only good bins as determined by Flags$_{hij}$.

$$\overline{I_{M\,h}^{F\,W}} = \frac{1}{\sum_{i=1}^{N_R^F} \sum_{j=1}^{N_j} Flags_{hij}} \sum_{i=1}^{N_R^F} \sum_{j=1}^{N_j} I_{hij}^{F\,W\,*}(\lambda_\circ) \tag{8.49}$$

where N_R^F is the number of rows in the measurement window being used for filter parameter determination and is given by:

$$N_R^F = \delta R^- + \delta R^+ + 1 \tag{8.50}$$

5. Normalize the model data using the mean intensities from the model data $\overline{I_{M\,h}^{F\,W}}$ and the mean intensities from the observations $\overline{I_{M\,h}^{T\,W}}$.

$$I_{hij}^{F\,W}(\lambda_\circ, \mu_e) = \frac{\overline{I_{M\,h}^{T\,W}}}{\overline{I_{M\,h}^{F\,W}}} I_{hij}^{F\,W\,*}(\lambda_\circ) \tag{8.51}$$

If FM_V=2,

FUNCTIONAL DESCRIPTION: This routine calculates the intensity incident on the hijth bin of the CCD as determined by the effect of the filter (omitting the Michelson effects). In it the intensity is first calculated on a pixel by pixel basis and then binned according to the binning used in the image being analysed. The mean intensity over each window in each field of view, $\overline{I^{F\,W}_{M\,h}}$, is then calculated and along with the mean intensity of the observed intensities, $\overline{I^{T\,W}_{M\,h}}$, used to normalize the result.

INPUT: The input parameters are:

- $\overline{I^{T\,W}_{M\,h}}$ - the mean intensity for each field of view (from A24434).
- $\theta^{F\,p\,W}_{hij}$ - the filter angles for each pixel in the reduced window being used for filter parameter determination (from A2441).
- $\mathrm{IM}^{m\,W}_{hi}$ - the intensities of the emission lines for each row being used for filter parameter determination (from A24431).
- $\lambda^{m\,p\,W}_{hij}$, $m = 1, 2, ..., 8$ - the Doppler shifted wavelengths for each pixel in the window being used for the filter determination.
- $\lambda_\circ$ - the wavelength at peak transmission at normal incidence, an input parameter.
- μ_e - the effective refractive index, an input parameter.
- $(\Delta\lambda)^A_\circ$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- fexp^A - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT: The output parameters are:

- $I^{F\,W}_{hij}(\lambda_\circ, \mu_e)$ - the model intensity incident on the hijth bin due to the filter alone.

HYPOTHESIS OF APPLICABILITY: It is assumed that the Lissberger formula provides an accurate model of the behaviour of the O_2 filter on WINDII.

CRITERIA OF APPLICABILITY: To be used for all estimations of the filter parameters.

TRANSFORMATION EQUATIONS: The steps in this function are:

1. Calculate the intensity $I^{F\,p\,m\,W}_{hij}(\lambda_\circ, \mu_e)$ at the CCD for each pixel in the reduced window being used for filter parameter determination, using

$$I^{F\,p\,m\,W}_{hij}(\lambda_\circ, \mu_e) = IM^{m\,W}_{hi} \times \mathcal{F}(\lambda_\circ, \mu_e; \theta^{F\,p\,W}_{hij}, \lambda^{m\,p\,W}_{hij}, (\Delta\lambda)^A_\circ, fexp^A) \tag{8.52}$$

   The evaluation of $\mathcal{F}$ is given in A244352.

2. Calculate the intensity due to each emission at each bin $I^{F\,m\,W}_{hij}(\lambda_\circ, \mu_e)$ by summing over the pixels contributing to each bin

$$I^{F\,m\,W}_{hij}(\lambda_\circ, \mu_e) = \sum_{pixels} I^{F\,p\,m\,W}_{hij}(\lambda_\circ, \mu_e) \tag{8.53}$$

3. Calculate the net intensity at each bin $I^{F\,W\,*}_{hij}(\lambda_\circ, \mu_e)$ by summing over the contributing emissions

$$I^{F\,W\,*}_{hij}(\lambda_\circ, \mu_e) = \sum_{m} I^{F\,m\,W}_{hij}(\lambda_\circ, \mu_e) \tag{8.54}$$

4. Calculate the mean intensity in each window of each field of view $\overline{I^{FW}_{Mh}}$ from the model data using only good bins as determined by Flags$_{hij}$.

$$\overline{I^{FW}_{Mh}} = \frac{1}{\sum_{i=1}^{N_R^F} \sum_{j=1}^{N_j} Flags_{hij}} \sum_{i=1}^{N_R^F} \sum_{j=1}^{N_j} I^{FW*}_{hij}(\lambda_o, \mu_e) \tag{8.55}$$

where N_R^F is the number of rows in the measurement window being used for filter parameter determination and is given by:

$$N_R^F = \delta R^- + \delta R^+ + 1 \tag{8.56}$$

5. Normalize the model data using the mean intensities from the model data $\overline{I^{FW}_{Mh}}$ and the mean intensities from the observations $\overline{I^{TW}_{Mh}}$.

$$I^{FW}_{hij}(\lambda_o, \mu_e) = \frac{\overline{I^{TW}_{Mh}}}{\overline{I^{FW}_{Mh}}} I^{FW*}_{hij}(\lambda_o, \mu_e) \tag{8.57}$$

A244352 - Calculation of the filter function $\mathcal{F}$

If FM_V=1,

<u>FUNCTIONAL DESCRIPTION</u>: The Lissberger formula is used to calculate the intensity for a prescribed set of input parameters. This function is called by A244351 and A311.

<u>INPUT</u>:

- θ - the input angle through the filter.
- λ - the wavelength at which the filter function is to be evaluated.
- $\tau(\theta)$ - the transmissivity of the filter as a function of the angle of incidence on the filter (provided as a function of three parameters, τ_1, τ_2, and τ_3, in the CDB).

- $\lambda_\circ$ - the wavelenght of peak transmission at normal incidence, an input parameter.
- μ_e^e - the effective refractive index, an input parameter (from the CDB). It is a function of aperture.
- $(\Delta\lambda)_\circ^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- fexp^A - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

OUTPUT: The output parameters are:

- $\mathcal{F}(\lambda_\circ;\, \theta, \lambda, \mu_e^e(\Delta\lambda)_\circ^A, fexp^A)$ - the filter function.

HYPOTHESIS OF APPLICABILITY: The Lissberger formula is an adequate description of the O_2 filter.

CRITERIA OF APPLICABILITY: Used for all calculations of the filter function in filter parameter determinations.

TRANSFORMATION EQUATIONS: The filter function is calculated as follows:

1. Calculate the peak transmissivity of the filter:

$$\tau(\theta) = \tau_1 + \tau_2\theta + \tau_3\theta^2 \tag{8.58}$$

2. Calculate the filter function

$$\mathcal{F}(\lambda_\circ;\theta,\lambda,\mu_e^e(\Delta\lambda)_\circ^A, fexp^A) \tag{8.59}$$

$$= \frac{\tau(\theta)}{1 + \left|\left[\frac{2(\lambda-\lambda_\circ)}{(\Delta\lambda)_\circ^A} + \frac{\lambda_\circ}{(\Delta\lambda)_\circ^A}\frac{\theta^2}{\mu_e^{e\,2}}\right]\right|^{fexp^A}}. \tag{8.60}$$

If FM_V=2,

<u>FUNCTIONAL DESCRIPTION</u>: The Lissberger formula is used to calculate the intensity for a prescribed set of input parameters. This function is called by A244351 and A311.

<u>INPUT</u>:

- θ - the input angle through the filter.
- λ - the wavelength at which the filter function is to be evaluated.
- $\tau(\theta)$ - the transmissivity of the filter as a function of the angle of incidence on the filter (provided as a function of three parameters, τ_1, τ_2, and τ_3, in the CDB).
- $\lambda_\circ$ - the wavelenght of peak transmission at normal incidence, an input parameter.
- μ_e - the effective refractive index, an input parameter.
- $(\Delta\lambda)_\circ^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture.
- fexp^A - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

<u>OUTPUT</u>: The output parameters are:

- $\mathcal{F}(\lambda_\circ, \mu_e; \theta, \lambda, (\Delta\lambda)_\circ^A, fexp^A)$ - the filter function.

<u>HYPOTHESIS OF APPLICABILITY</u>: The Lissberger formula is an adequate description of the O_2 filter.

CRITERIA OF APPLICABILITY: Used for all calculations of the filter function in filter parameter determinations.

TRANSFORMATION EQUATIONS: The filter function is calculated as follows:

1. Calculate the peak transmissivity of the filter:

$$\tau(\theta) = \tau_1 + \tau_2\theta + \tau_3\theta^2 \tag{8.61}$$

2. Calculate the filter function

$$\mathcal{F}(\lambda_\circ, \mu_e; \theta, \lambda, (\Delta\lambda)_\circ^A, fexp^A) \tag{8.62}$$

$$= \frac{\tau(\theta)}{1 + \left|\left[\frac{2(\lambda-\lambda_\circ)}{(\Delta\lambda)_\circ^A} + \frac{\lambda_\circ}{(\Delta\lambda)_\circ^A}\frac{\theta^2}{\mu_e^2}\right]\right|^{fexp^A}}. \tag{8.63}$$

8.4 A2444 - Interpolate to obtain daily filter parameters

If FM_V=1,

FUNCTIONAL DESCRIPTION: The daily record of filter parameter is used to provide a functional fit for this parameter. This fit is then used to provide the filter parameter $\lambda_\circ$ at any time during the day. A parabolic fit is calculated for each day and night segment for each orbit.

INPUT: The input parameters are:

- $\lambda_\circ^A(UT)$ - Values of the wavelength of the peak transmission at normal incidence of the filter best characterizing the behaviour of the filter as a function of UT (from A24435).

OUTPUT: The output parameters are:

- $C^{\lambda_\circ A}_{r\ orb}$ - the coefficients of the quadradic expression giving the filter parameter $\lambda_\circ$ as a function of universal time ($r = 1, \ldots, 3$) for each day and night orbit segment ($orb = 1, \ldots, \#$ orbits). The coefficients are a function of aperture.

HYPOTHESIS OF APPLICABILITY: It is assumed that the variation of the filter parameters with time during each day and night orbit segment is smooth and adequately described using a quadratic function.

CRITERIA OF APPLICABILITY: To be applied each O_2 day.

TRANSFORMATION EQUATIONS:

- Using all the $\lambda^A_\circ(UT)$ for each aperture, A, for each day and night orbit segment calculate the quadratic fit for $\lambda_\circ$ verses UT, the coefficients for this fit being $C^{\lambda_\circ A}_{r\ orb}$ ($r = 1, \ldots, 3$).

Note: the coefficients of the quadratic fit are designated as follows:

$$\lambda^A_\circ(UT) = C^{\lambda_\circ A}_{1\ orb} + C^{\lambda_\circ A}_{2\ orb} \times UT + C^{\lambda_\circ A}_{3\ orb} \times UT^2 \qquad (8.64)$$

with a similar form for the remaining fits.

If FM_V=2,

FUNCTIONAL DESCRIPTION: The daily record of filter parameters is used to provide a functional fit for these parameters. This fit is then used to provide the filter parameters $\lambda_\circ$ and μ_e at any time during the day. A parabolic fit is calculated for each day and night segment for each orbit.

INPUT: The input parameters are:

- $\lambda_\circ^A(UT)$ - Values of the wavelength of the peak transmission at normal incidence of the filter best characterizing the behaviour of the filter as a function of UT (from A24435).

- $\mu_e^A(UT)$ Values of the effective refractive index best characterizing the behaviour of the filter as a function of UT (from A24435).

OUTPUT: The output parameters are:

- $C_{r\,orb}^{\lambda_\circ A}$ - the coefficients of the quadradic expression giving the filter parameter $\lambda_\circ$ as a function of universal time ($r = 1, \ldots, 3$) for each day and night orbit segment ($orb = 1, \ldots, \#$ orbits). The coefficients are a function of aperture.

- $C_{r\,orb}^{\mu_e A}$ - the coefficients of the quadradic expression giving the filter parameter μ_e as a function of universal time ($r = 1, \ldots, 3$) for each day and night orbit segment ($orb = 1, \ldots, \#$ orbits). The coefficients are a function of aperture.

HYPOTHESIS OF APPLICABILITY: It is assumed that the variation of the filter parameters with time during each day and night orbit segment is smooth and adequately described using a quadratic function.

CRITERIA OF APPLICABILITY: To be applied each O_2 day.

TRANSFORMATION EQUATIONS:

- Using all the $\lambda_\circ^A(UT)$ for each aperture, A, for each day and night orbit segment calculate the quadratic fit for $\lambda_\circ$ verses UT, the coefficients for this fit being $C_{r\,orb}^{\lambda_\circ A}$ ($r = 1, \ldots, 3$).

- **Using all the $\mu_e^A(UT)$ for each aperture for each day and night orbit segment, calculate the quadratic fit for μ_e verses UT, the coefficients for this fit being $C_{r\,orb}^{\mu_e\,A}$ $(r = 1,\ldots,3)$.**

Note: the coefficients of the quadratic fit are designated as follows:

$$\lambda_\circ^A(UT) = C_{1\,orb}^{\lambda_\circ\,A} + C_{2\,orb}^{\lambda_\circ\,A} \times UT + C_{3\,orb}^{\lambda_\circ\,A} \times UT^2 \qquad (8.65)$$

with a similar form for the remaining fits.

5. Calculate the value of x_{hijk} for each bin in the measurement.

9.1 A311 - Calculate filter transmission

If FM_V=1,

FUNCTIONAL DESCRIPTION: In this subroutine the O_2 filter transmission for all the pixels in the observation window are calculated using the Lissberger formula, equation 8.1.

INPUT: The input parameters are:

- N_i - number of mesurement bins or rows in the vertical.
- N_j - number of mesurement bins or rows in the horizontal.
- NVB - bin dimension in the vertical in pixels.
- NHB - bin dimension in the horizontal in pixels.
- NVO - vertical offset of the measurement window from the bottom of the CCD in bins.
- NHO - horizontal offset of the measurement window from the outside edges of the CCD.
- NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.
- NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.
- θ_{hij}^{Fp} - the filter angles for each pixel on the CCD (from A2441).

- Z_{hijk} - the geodetic altitude for each bin.

- $C^{\lambda_\circ A}_{r\,orb}$ - the coefficients of the quadradic expression giving the filter parameter $\lambda_\circ$ as a function of universal time ($r = 1, \ldots, 3$) for each day and night orbit segment. The coefficients are a function of aperture.

- μ^e_e - the effective refractive index, an input parameter (from the CDB). It is a function of aperture.

- $(\Delta\lambda)^A_\circ$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture (from A2444).

- fexp^A - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.

- λ_m, $m = 1, 2, ..., 8$ - the eight emission wavelengths contributing to the intensity measured with the O_2 filter (from CDB).

- vps^p_{hij} - projected spacecraft velocity along line of sight, from A2221.

- vre^p_{hij} - velocity of the earth rotation at tangent point on a latitude circle from A2221.

- c - the speed of light ($= 2.99792459 \times 10^8$ m/s)

<u>OUTPUT</u>: The output parameters are:

- $\mathcal{F}^{m\,p}_{hij}$ - the filter transmission for each wavelength at each pixel in the measurement window.

<u>HYPOTHESIS OF APPLICABILITY</u>: It is assumed that the Lissberger formula adequately describes the behaviour of the O_2 filter.

CRITERIA OF APPLICABILITY: To be used in the analysis of each O_2 measurement.

TRANSFORMATION EQUATIONS: The steps in the calculation of the filter transmission function are:

1. Select the angles of incidence on the filter for each pixel in the measurement window.
2. Determine the Doppler shifted wavelengths, λ^{mp}_{hij}, for the eight O_2 emissions, contributing to the intensity on the CCD as done in A24433, but for the full measurement window.
3. Determine the filter transmission for each pixel in the measurement window and for the eight emissions of interest by:
    - (a) Calculating appropriate λ_o for the universal time of the measurement using the coefficients $C^{\lambda_o A}_{r\,orb}$. See A2444 for a description of the evaluation of these parameters.
    - (b) Calculate $\mathcal{F}^{mp}_{hij}$ using the function defined in A244352 for FM_V=1.

$$\mathcal{F}^{mp}_{hij} = \mathcal{F}(\lambda_o; \mu^c_e, (\Delta\lambda)^A_o, fexp^A, \theta^{Fp}_{hij}, \lambda^{mp}_{hij}) \qquad (9.1)$$

If FM_V=2,

FUNCTIONAL DESCRIPTION: In this subroutine the O_2 filter transmission for all the pixels in the observation window are calculated using the Lissberger formula, equation 8.1.

INPUT: The input parameters are:

- N_i - number of mesurement bins or rows in the vertical.

- **N_j - number of mesurement bins or rows in the horizontal.**
- **NVB - bin dimension in the vertical in pixels.**
- **NHB - bin dimension in the horizontal in pixels.**
- **NVO - vertical offset of the measurement window from the bottom of the CCD in bins.**
- **NHO - horizontal offset of the measurement window from the outside edges of the CCD.**
- **NV_{fov} - the number of pixels in the vertical on the useable region of the CCD.**
- **NH_{fov} - the number of pixels in the horizontal on the useable region of the CCD for each field of view.**
- **$\theta^{F\,p}_{hij}$ - the filter angles for each pixel on the CCD (from A2441).**
- **Z_{hijk} - the geodetic altitude for each bin.**
- **$C^{\lambda_o\,A}_{r\,orb}$ - the coefficients of the quadradic expression giving the filter parameter λ_o as a function of universal time ($r = 1, \ldots, 3$) for each day and night orbit segment. The coefficients are a function of aperture.**
- **$C^{\mu_e\,A}_{r\,orb}$ - the coefficients of the quadradic expression giving the filter parameter μ_e as a function of universal time ($r = 1, \ldots, 3$) for each day and night orbit segment. The coefficients are a function of aperture (from A2444).**

- $(\Delta\lambda)_0^A$ - the effective halfwidth of the filter (from the CDB). It is a function of aperture (from A2444).
- fexp^A - the exponent in the Lissberger formula (from the CDB). It is a function of aperture.
- λ_m, $m = 1, 2, ..., 8$ - the eight emission wavelengths contributing to the intensity measured with the O_2 filter (from CDB).
- vps_{hij}^p - projected spacecraft velocity along line of sight, from A2221.
- vre_{hij}^p - velocity of the earth rotation at tangent point on a latitude circle from A2221.
- c - the speed of light ($= 2.99792459 \times 10^8$ m/s)

<u>OUTPUT</u>: The output parameters are:

- $\mathcal{F}_{hij}^{mp}$ - the filter transmission for each wavelength at each pixel in the measurement window.

<u>HYPOTHESIS OF APPLICABILITY</u>: It is assumed that the Lissberger formula adequately describes the behaviour of the O_2 filter.

<u>CRITERIA OF APPLICABILITY</u>: To be used in the analysis of each O_2 measurement.

<u>TRANSFORMATION EQUATIONS</u>: The steps in the calculation of the filter transmission function are:

1. Select the angles of incidence on the filter for each pixel in the measurement window.

2. **Determine the Doppler shifted wavelengths, λ_{hij}^{mp}, for the eight O_2 emissions, contributing to the intensity on the CCD as done in A24433, but for the full measurement window.**

3. **Determine the filter transmission for each pixel in the measurement window and for the eight emissions of interest by:**

    (a) **Calculating appropriate $\lambda_\circ$ and μ_e for the universal time of the measurement using the coefficients $C_{r\,orb}^{\lambda_\circ\,A}$ or $C_{r\,orb}^{\mu_e\,A}$ as appropriate. See A2444 for a description of the evaluation of these parameters.**

    (b) **Calculate $\mathcal{F}_{hij}^{mp}$ using the function defined in A244352.**

$$\mathcal{F}_{hij}^{mp} = \mathcal{F}(\lambda_\circ, \mu_e; (\Delta\lambda)_\circ^A, fexp^A, \theta_{hij}^{Fp}, \lambda_{hij}^{mp}) \qquad (9.2)$$

9.2 A312 - Prepare instrument phase files

<u>FUNCTIONAL DESCRIPTION</u>: The contribution to the observed phase from all sources other than the atmospheric wind relative to the earth must be determined in order to unambiguously determine this quantity. In this routine two components to this contribution namely the phase steps and the instrument phase excluding the phase step (see A221, equation 5.2 for definitions of the phase quantities) are determined for each pixel in the measurement window and for each emission.

<u>INPUT</u>: The input parameters are:

- **$\phi_{B\,hi}^{Ap}(a_{0\,hi}^A, a_{1\,hi}^A, a_{2\,hi}^A, a_{3\,hi}^A, a_{4\,hi}^A, a_{5\,hi}^A)$ - an array of 6 parameters for each row and FOV giving the expansion coefficients for a 5th order polynomial fit to the phase variation across each row in each field of view on the CCD. This is provided in the CDB.**