Range Reference Atmosphere 2013

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TABLE OF CONTENTS

1.0 INTRODUCTION
1.1 Definition of a Range Reference Atmosphere
1.2 Purpose
1.3 History
1.4 Scope, Contents, and Arrangement of Data Tables

2.0 METHODOLOGY OVERVIEW

3.0 STEP 1: SELECT INPUT DATA

4.0 STEP 2: INITIALIZE DATA AND PERFORM QUALITY CONTROL
4.1 Out of Bounds Value Check
4.2 Surface level Check
4.3 Duplicate Profile Check
4.4 Missing Data Check
4.5 Minimum Number of Valid Data Levels Check
4.6 Maximum Data Gap Interval Check
4.7 Wind Speed Shear Check
4.8 Negative Delta-Z Check
4.9 Visual Inspection Check Based on Subject Matter Expertise

5.0 STEP 3: INTERPOLATE PROFILE DATA
5.1 Establish Output Altitude Grid
5.2 Compute Geopotential Heights for Output Grid Altitudes
5.2.1 Compute Latitude-Dependent Surface Gravity
5.2.2 Compute Vertical Derivative of Gravity at Surface
5.2.3 Compute Effective Earth Radius
5.2.4 Compute Geopotential Heights
5.3 Compute Wind Components
5.4 Interpolate Wind Speed and Wind Components to Output Grid
5.5 Interpolate Pressure to Output Grid
5.6 Interpolate Temperature and Dewpoint to Output Grid

6.0 STEP 4: COMPUTE DERIVED QUANTITIES
6.1 Compute Vapor Pressure
6.2 Compute Virtual Temperature
6.3 Compute Density

7.0 STEP 5: COMPUTE STATISTICS

8.0 STEP 6: PERFORM DIAGNOSTIC TESTING

9.0 **STEP 7: PERFORM VALIDATION TESTING**
9.1 Skewness Limit Tests
9.2 **B**uell Relationship Tests
9.3 Gas Law Reconstruction Test
9.4 Wind Speed Reconstruction Test

10.0 **STEP 8: CREATE FINAL DATA PRODUCTS**

11.0 **SUMMARY OF RESULTS**
11.1 Diagnostic Testing Results
11.2 Validation Testing Results
11.3 Statistical Parameter Profiles

APPENDIX I **EARTH-GRAM FORMATTED RRA DATA TABLES**

APPENDIX II **FIGURES**

REFFERENCES

1.0 INTRODUCTION

1.1 Definition of a Range Reference Atmosphere

A reference atmosphere is a statistical description of the Earth's atmosphere derived from upper-air measurements over some geographical area. Typically, reference atmospheres provide mean values and some measures of variability for a number of atmospheric state variables, such as pressure, density, temperature, wind speed, etc. The first reference atmosphere, developed in the 1920's [1], was referred to as a "standard atmosphere." Standard atmospheres are intended to be applicable over large spatial domains (mid-latitudes, for example). For higher-fidelity characterization of the atmosphere at a particular location, site-specific reference atmospheres were later developed. This type of reference atmosphere is referred to as a Range Reference Atmosphere (RRA). RRAs are, formally, a product of the Range Commander's Council (RCC) Meteorology Group (RCC-MG). The Marshall Space Flight Center (MSFC) Natural Environments (NE) Branch has developed a new series of RRAs on behalf of the RCC-MG. This document details the development methodology and the results obtained for the 2013 Vandenberg Air Force Base (VAFB) RRA.

1.2 Purpose

A series of revised and expanded RRAs are to be published for locations of interest to the RCC. These publications are to serve as an authoritative reference source on certain upper air statistics and as atmospheric models for a particular range site (location). The technical usefulness of these documents for the ranges, range users, U.S. aerospace industries, and the scientific community is recognized because of the standardization of the development techniques and the presentation of the tabulations.

1.3 History

Many RRA datasets have been produced over the years. The Inter-Range Instrumentation Group Meteorology Working Group (IRIG-MWG), the organizational predecessor to the RCC-MG, published several RRAs from 1963 through 1974. Beginning in 1983, the RCC-MG published a new updated series of RRAs (RRA version 1983) to take advantage of improved measurement systems and data processing capabilities [2]. A standardized process was implemented to generate this series of RRAs, in contrast to previous versions, which were generated using non-standardized, site-specific methodologies. Beginning in 2002, a second series of RRA updates was generated by the Air Force Combat Climatology Center (now known as the 14th Weather Squadron) [3]. These datasets were published by the RCC-MG in 2006 (RRA version 2006). The RCC-MG intends to produce new RRA versions quasi-periodically to maintain the best possible current representations of the upper atmospheres (surface to 30 km altitude) at selected ranges of interest. In 2012, MSFC-NE began development of new RRA update versions, resulting in the current document and associated data tables. These new datasets will be referred to as RRA version 2013.

1.4 Scope, Contents, and Arrangement of Data Tables

The RRA contains tabulations for monthly and annual statistics. Means (μ), medians, standard deviations (σ), and skewness coefficients are given for wind speed (WS), atmospheric pressure (P), air temperature (T), density (D), water vapor pressure (VP), virtual temperature (Tv), and dewpoint temperature (Td). Means, medians, and standard deviations are given for the zonal (U) and meridional (V) wind components. The linear (product moment) correlation coefficient (R_{UV}) between the U and V wind components is also given. Counts of the number of observations used in the computations are given for each month and altitude level.

The statistical quantities are computed at the surface elevation (relative to mean sea level), and at 0.5 km intervals up to 30 km altitude. Table 1 summarizes the various statistical quantities computed for each meteorological parameter.

Table 1 Range Reference Atmosphere Physical Parameters and Statistical Quantities

Meteorological Parameter	Statistical Quantities
Geometric altitude (Z)	Vertical coordinate (independent variable)
Zonal wind component (U)	Mean, median, standard deviation
Meridional wind component (V)	Mean, median, standard deviation
Wind component correlation (R_{UV})	Linear product-moment correlation
Wind speed (WS)	Mean, median, standard deviation, skewness
Number of wind observations	Arithmetic Sum
Atmospheric pressure (P)	Mean, median, standard deviation, skewness
Atmospheric temperature (T)	Mean, median, standard deviation, skewness
Atmospheric density (D)	Mean, median, standard deviation, skewness
Number of thermodynamic observations	Arithmetic Sum
Water vapor pressure (VP)	Mean, median, standard deviation, skewness
Virtual temperature (Tv)	Mean, median, standard deviation, skewness
Dewpoint temperature (Td)	Mean, median, standard deviation, skewness
Number of moisture observations	Arithmetic Sum

In addition to the primary RRA spreadsheet file, auxiliary text files are produced containing the same data, but formatted for use in the Earth Global Reference Atmospheric Model (Earth-GRAM), which is an MSFC-NE analysis tool. A separate text document is produced that lists the inventory of individual profiles that were used in the final dataset production.

2.0 METHODOLOGY OVERVIEW

In order to facilitate diagnostic analysis and minimize duplicating run-time overhead, the RRA production follows a series of discrete computational steps. Each step performs a specific

function and the outputs from one step are used as inputs for the next subsequent step. A listing of the various steps is shown in Table 2, with details for each step given in the following sections.

Table 2 Steps in Range Reference Atmosphere Production

Step	Description
1	Define/Obtain Input Data
2	Perform Data Initialization
3	Interpolate Profile Data
4	Compute derived quantities
5	Compute Statistics
6	Perform Diagnostic Testing
7	Perform Validation Testing
8	Write Final Output Files

3.0 STEP 1: DEFINE/OBTAIN INPUT DATA

Input data consist of upper-air profiles taken at Vandenberg Air Force Base. Data from synoptic balloon flights (archived at the National Climatic Data Center) are combined with mission-specific balloon flights taken by the Real Time Meteorological Profiling System (RTAMPS) to give a single input dataset with a combined period of record from January 1, 1990 through January 7, 2013. The unprocessed data contain 12,417 individual profiles. The data have been previously archived in an MSFC-NE standard referred to here as "master file format." In this format, data are written as variable-length text strings, with one profile per line. Each profile string starts with a meta-data section giving the year, month, day of the month, and hour of the balloon observation, plus the number of data levels in the profile. Following the meta-data are sequential altitude/level data sections containing values for Z, WS, WD, T, Td, and P. These master files have been compiled to support various analyses including RRA development. While initial quality control (QC) procedures are performed on the raw data during the master file compilation process (which are not described here), additional RRA-specific QC procedures are performed, as described in the following section.

4.0 STEP 2: INITIALIZE DATA AND PERFORM QUALITY CONTROL

Data initialization involves preprocessing and reformatting the master file data to optimize subsequent computational efficiency. Each profile is read from the master file and a series of QC checks are performed to identify and remove bad data. Any profiles identified with bad data are removed before any further computations are performed. In addition, the units of altitude are converted from feet to kilometers, and the units of wind speed are converted from knots to meters per second. The resulting set of initialized profiles is written to a new text file for use in

subsequent processing. The individual QC procedures performed during step 2 are discussed in the following sections.

4.1 Out of Bounds Value Check

When the profiles are being read in, the master file data values are checked against a set of realistic value constraints. Upper and lower constraint limits applied to each parameter are shown in Table 3. Some of these limits correspond to physically unrealistic values. These include the lower WS range, both upper and lower wind direction, WD, ranges, and the lower P range. Other limits correspond to values that were deemed by subject matter experts (SMEs) to be outside the range of expected observable values. These include the upper WS range, both upper and lower T ranges, both upper and lower Td ranges, and the upper P range. Any values outside these limiting bounds are replaced with a value representing the Institute of Electrical and Electronics Engineers floating point standard for Not-a-Number (NaN) [4]. One additional check is performed on dewpoint based on the observed temperature. If the temperature at a given level is below -60˚ C, then the Td for that level is treated as missing data. The rationale for this is that dewpoint instrument sensitivity decreases rapidly for temperatures below -60˚ C. At these temperatures, it is reasonable to assume that the moisture content in the air is negligible.

Table 3 Out of Bounds Value Quality Control Check Constraint Limits

		Out of Bounds Value Limits	
Parameter	**Units**	**Lower Limit**	**Upper Limit**
Wind Direction	Deg, clockwise from North	WD < 0	WD > 360
Wind Speed	m/s	WS < 0.0	WS > 200
Temperature	C	T < -100	T > 70
Dewpoint	C	Td < -100	Td > 70
Pressure	mb	P < 0	P > 1200

4.2 Surface level Check

Profiles are required to start with valid data values within 0.1 km of the nominal surface elevation of 0.1 km. Any profile with a lowest reporting altitude above this limit is removed and not used for statistical computations.

4.3 Duplicate Profile Check

Often, data from the same balloon flight are represented in the archive at multiple vertical resolutions. For example, a given profile may be present in both 100 ft and 1000 ft resolutions. In these instances, the master file contains two profile entries with time stamps separated by only

a minute or two. When data from a given balloon flight exists in multiple resolutions, only the data with the lowest resolution is retained.

4.4 Missing Data Check

Various "missing data" flags (for example, -999.99) are occasionally present in the data archive in place of valid data entries. Any missing data flags are replaced with NaN.

4.5 Minimum Number of Valid Data Levels Check

A test is performed to ensure that each input profile contains at least five levels with valid data values. This test is performed independently for the parameters WS, T, Td, and P. Any profile containing less than five levels with valid observations of WS, T, Td, or P are removed. Note that this QC check does not require a profile to have at least five levels containing valid observations of all test parameters simultaneously at that same level.

4.6 Maximum Data Gap Interval Check

A test is performed to ensure that no data gaps larger than 5 km were present. Any profiles with data gaps (altitude differences between adjacent levels with valid data values) larger than 5 km are removed. This test is performed sequentially for WS, T, Td, and P.

4.7 Wind Speed Shear Check

A maximum wind shear limit is established with a value of 0.3 s^{-1}. Any profile containing wind speed shears between adjacent data reporting levels that exceeded the established limit is removed.

4.8 Negative Altitude Change Between Adjacent Levels Check

Occasionally a profile in the master file is noted to be corrupt as though portions of two separate profiles are written on a single line. Typically, this is manifested as a profile that appears valid up to some given level, after which the profile data is over-written by a second full profile. In these instances, the given, N^{th} data level corresponds to a given altitude, say Z_N, while the next subsequent, $(N+1)^{th}$ data level corresponds to a second altitude, Z_{N+1}, where $Z_{N+1} < Z_N$. Any profiles where $Z_{N+1} < Z_N$, for any adjacent levels N and N+1, are removed.

4.9 Visual Inspection Check Based on Subject Matter Expertise

At various points in the data processing, certain profiles are noted as suspect based on assorted computational anomalies. For example, on occasion, a text string will exist in one of a given profile's data fields, causing the processing program to terminate due to an inability to interpret the text string as a numerical value. In these instances, the profile is inspected manually to determine the source of the anomaly. Those profiles that were deemed to be corrupted or otherwise unacceptable are removed. This QC check is an event-driven process that is active both prior to and subsequent to statistical computations.

5.0 STEP 3: INTERPOLATE PROFILE DATA

The desired vertical resolution for the RRA tables is established as 0.5 km. Thus, individual profiles must be interpolated to this grid resolution. Once all values have been interpolated onto the output grid resolution, the profiles are written to a third text file. The individual tasks in the interpolation process are detailed in the following sections.

5.1 Establish Output Altitude Grid

An output grid of altitude values, Z_{out}, is established covering the vertical domain from surface to 30 km with a 0.5 km vertical resolution. The lowest grid value is set at the nominal surface height of 0.005 km.

5.2 Compute Geopotential Heights for Output Grid Altitudes

To facilitate interpolations, an array of geopotential heights, H_{out}, is computed, with elements corresponding to each element of Z_{out}. The process of computing geopotential heights, adapted from [2] and [5], is detailed the following sections.

5.2.1 Compute Latitude-Dependent Surface Gravity

Considering the Earth as a reference ellipsoid, the acceleration of gravity, g, at the surface, and at latitude, ϕ, is approximated by the following equation:

$$g_{\phi} = 9.780356 \times (1 + 5.2885E^{-3} \times sin^2\phi - 5.9E^{-6} \times sin^2 2\phi) \qquad \text{Eq. 1}$$

5.2.2 Compute Vertical Derivative of Gravity

Gravitational acceleration is known to decrease with altitude. An expression for the rate of change of g with altitude, evaluated at the surface is obtained from the following equation:

$$\left(\frac{\partial g}{\partial Z}\right)_{Z=0} = -3.085462E^{-6} + 2.27E^{-9} \times cos2\phi - 2E^{-12} \times cos4\phi \qquad \text{Eq. 2}$$

Although this derivative is explicitly only valid at the surface, it has been shown to be valid for the current application up to 600 km altitude [5].

5.2.3 Compute Effective Earth Radius

An effective radius, $R_{EFF,}$ can be defined that takes into account the non-spherical shape of the Earth and centrifugal forces caused by the Earth's rotation. This radius does not necessarily correspond to the actual Earth radius at a given point on the surface. The effective radius is computed using the following equation:

$$R_{EFF} = \frac{-2g_{\phi}}{\left(\frac{\partial g}{\partial Z}\right)_{Z=0}} \qquad \text{Eq. 3}$$

5.2.4 Compute Geopotential Heights

The geopotential height, H, as a function of altitude is then computed using the following:

$$H_z = \frac{g_{\phi}}{g_0} \times R_{EFF} \times \frac{Z}{R_{EFF}+Z} \qquad \text{Eq. 4}$$

In this expression, g_0 is the reference gravitational acceleration with a value of 9.80665 m/s^2.

5.3 Compute Wind Components

Zonal and meridional wind components are computed from WS and WD at each input grid altitude using the following equations:

$$U = -WS \times \sin(WD) \qquad \text{Eq. 5}$$
$$V = -WS \times \cos(WD) \qquad \text{Eq. 6}$$

5.4 Interpolate Wind Speed and Wind Components to Output Grid

Wind parameters (WS, U, and V) are interpolated linearly with respect to geopotential height. First, an array geopotential heights, H_{in}, is computed (as in Section 5.2) with elements corresponding to each altitude in the input grid. Next, for each Nth level in the output grid, the output grid geopotential height for that level, computed in section 5.2, is noted as $H_{out,N}$. Then, the closest bounding geopotentials (above, H_A, and below, H_B) from the input grid are selected as follows:

H_A = minimum of H_{in} values where $H_{in} > H_{out,N}$.

H_B = maximum of H_{in} values where $H_{in} \leq H_{out,N}$.

Further, the input grid altitude array indices for H_A and H_B are defined as I_A and I_B such that

$H_{in}(I_A) = H_A$, and
$H_{in}(I_B) = H_B$.

Then, upper and lower input grid values for WS, U, and V are determined as the array elements defined by the indices I_A and I_B:

$WS_A = WS(I_A)$
$WS_B = WS(I_B)$
$U_A = U(I_A)$
$U_B = U(I_B)$
$V_A = V(I_A)$
$V_B = V(I_B)$.

Now, a term, C_1, can be defined where $C_1 = (H_{out,N} - H_B)/(H_A - H_B)$. Then, the Nth interpolated values for WS, U, and V are computed:

$$WS_N = WS_B + (WS_A - WS_B) * C_1. \quad \text{Eq. 7}$$
$$U_N = U_B + (U_A - U_B) * C_1. \quad \text{Eq. 8}$$
$$V_N = V_B + (V_A - V_B) * C_1. \quad \text{Eq. 9}$$

5.5 Interpolate Pressure to Output Grid

Pressures are interpolated from each level of the input grid onto the output grid by applying a form of the hypsometric equation shown in [2]. First, H_A, H_B, I_A, and I_B are determined as in Section 5.4. Then, P_B is computed as $P_B = P(I_B)$. Next, virtual temperatures need to be computed for the two input grid levels corresponding to I_A and I_B. The process of computing virtual temperature is detailed in Section 6.2 below. It is convenient to define the upper and lower bounding values for virtual temperature as $Tv_A = Tv(I_A)$ and $Tv_B = Tv(I_B)$. Then, the layer-averaged virtual temperature is given by $Tv_{AVE} = (Tv_A+Tv_B) / 2$. Finally, the interpolated pressure, P_{OUT}, is computed using the following equation:

$$P_{OUT} = P_B \times EXP\left(\frac{H_B - H_A}{29.2712617 \times TV_{AVE}}\right). \quad \text{Eq. 10}$$

5.6 Interpolate Temperature and Dewpoint to Output Grid

Temperatures and dewpoints are interpolated logarithmically with respect to pressure. First, H_A, H_B, I_A, and I_B are determined for each output grid level, as in Section 5.4. Then, the upper and lower bounding values for temperature and dewpoint are determined as follows:

$T_A = T(I_A)$.

T_B = $T(I_B)$.
TD_A = $TD(I_A)$.
TD_B = $TD(I_B)$.

Next, it is convenient to define a term, C_2, where $C_2 = [\ln(P_{OUT}) - \ln(P_B)] / [\ln(P_A) - \ln(P_B)]$. Then, the interpolated values of T and TD are computed as follows:

$$T_{OUT} = T_B + (T_A - T_B) * C_2. \quad \text{Eq. 11}$$
$$Td_{OUT} = Td_B + (Td_A - Td_B) * C_2. \quad \text{Eq. 12}$$

6.0 STEP 4: COMPUTE DERIVED QUANTITIES

Once all profiles of WS, U, V, T, Td, and P have been interpolated to the output grid resolution, values for the additional derived quantities of VP, Tv, and D are computed as shown in the following sections. These equations and methods are adapted from [2].

6.1 Compute Vapor Pressure

Vapor pressure is computed from dewpoint using the following equation:

$$VP_{OUT} = 6.112 \times 10^{\left[\frac{17.67 \times TdC}{(TdC+243.5)}\right]} \quad \text{Eq. 13}$$

In this equation, TdC is the dewpoint expressed in units of degrees C. For upper levels where Td is undefined (NaN), VP is set identically equal to zero.

6.2 Compute Virtual Temperature

To compute virtual temperature, first, the water vapor mixing ratio, w, is computed using the following equation:

$$w = \epsilon \times \frac{VP}{P - VP}, \quad \text{Eq. 14}$$

where ϵ is the dimensionless ratio of the molecular weight of water vapor to the molecular weight of dry air, with a constant value of 0.622. Then, virtual temperature (in Kelvins) is computed using the following equation:

$$Tv_{OUT} = T \times \frac{1 + \frac{w}{\epsilon}}{1 + w} \quad \text{Eq. 15}$$

6.3 Compute Density

Density is computed from output pressure and virtual temperature values using the following equation:

$$D_{OUT} = 348.36787 \times \frac{P_{OUT}}{Tv_{OUT}} \qquad \text{Eq. 16}$$

7.0 STEP 5: COMPUTE STATISTICS

Computation of the RRA statistics is straight forward. The collected data from all profiles are segregated by month and altitude level. Then, for each month and altitude combination, mean values, median values, and standard deviations are computed for WS, U, V, P, T, D, VP, Tv, and Td. Skewness coefficients are computed for WS, P, T, D, VP, Tv, and Td. Numbers of observations are counted for WS, P, T, and Td. Lastly, the correlation between the U and V wind components is calculated. Data values of NaN are not used in these computations. All computed values are tabulated in an intermediate output file.

8.0 STEP 6: PERFORM DIAGNOSTIC TESTING

Diagnostic testing is performed individually for the variables WS, U, V, T, P, and Td. After computing monthly mean values and standard deviations at each RRA altitude, all profiles of a given variable for a given month are plotted together along with the μ +/- 6σ envelopes. All profiles with values that exceeded the envelope limits at any level are flagged for removal.

After removing these profiles, step 5 is repeated to give a new set of RRA statistics. Then, step 6 is repeated with new envelopes derived from the new means and standard deviations. Steps 5 and 6 are iterated until no profiles exceed any of the μ +/- 6σ envelopes.

9.0 STEP 7: PERFORM VALIDATION TESTING

Once a set of RRA statistics successfully passes the diagnostic testing process, an additional series of tests are performed to establish the validity of the statistical values. The individual tests are described in detail in the following sections. Some of these tests have quantified success criteria while others require the judgment of SMEs to determine pass/fail conditions. It should be noted that a failure of one of these validation tests does not suggest a clear remediation process. For example, no individual profiles are indicated as the cause of the failure condition. Rather, these tests were used to indicate the presence of some problem. Once detected, the problem is addressed through in-depth manual inspection of the input data and various idiomatic analyses of the constituent data values. Any erroneous profiles discovered to be supporting the failure condition are removed from the input database and the development process is repeated beginning with step 5. This process is iterated until no validation test failures are noted.

9.1 Skewness Limit Tests

Bounds are placed on the acceptable skewness coefficients for WS, T, P, Td, and D. The threshold values applied to these tests are shown in Table 4. The success criterion for these tests is the condition that no skewness coefficient exceeded the limits defined in the table, for any month or altitude.

Table 4 Thresholds for Skewness Limit Tests

Parameter	Valid Skewness Condition	
WS	SKEW ≤ 4.0	for μ_{WS} < 15 m/s
	SKEW ≤ 2.5	for μ_{WS} ≥ 15 m/s
P	-2.5 ≤ SKEW ≤ 2.5	
T	-2.5 ≤ SKEW ≤ 2.5	
D	-3.5 ≤ SKEW ≤ 3.5	
Td	-2.5 ≤ SKEW ≤ 2.5	

9.2 Buell Relationship Tests

Buell [6] derived a set of relationships based on the statistics of P, T, and D. These relationships define equalities between various terms involving the mean values (μ_P, μ_T, μ_D), the standard deviations (σ_P, σ_T, σ_D), and correlations between the variables for pressure and temperature (R_{PT}), pressure and density (R_{PD}), and temperature and density (R_{TD}). The three Buell relationships shown below are applied for these tests.

(Buell relationship #1) $$\frac{\sigma_p}{\mu_P} \cdot r_{PD} = \frac{\sigma_D}{\mu_D} + \frac{\sigma_T}{\mu_T} \cdot r_{TD}.$$ Eq. 17

(Buell relationship #2) $$\frac{\sigma_p}{\mu_P} \cdot r_{PT} = \frac{\sigma_T}{\mu_T} + \frac{\sigma_D}{\mu_D} \cdot r_{TD}.$$ Eq. 18

(Buell relationship #3) $$\frac{\sigma_p}{\mu_P} = \frac{\sigma_D}{\mu_D} \cdot r_{PD} + \frac{\sigma_T}{\mu_T} \cdot r_{PT}.$$ Eq. 19

These tests are implemented individually for each relationship by computing each side of the equations using monthly RRA values (at each altitude), and subtracting the right hand side from the left hand side. These difference values are then plotted as a function of altitude and any significant deviations are noted. The success criterion for these tests is the condition that no deviations are present of sufficient magnitude to be judged by the SME to be problematic.

9.3 Gas Law Reconstruction Test

An expression for the gas constant, R_g, can be derived from the ideal gas law:

$$R_g = \frac{P}{D \cdot T}. \qquad \text{Eq. 20}$$

For this test, RRA monthly mean values are used to compute R_g at all altitudes, and the computed values are compared to the accepted value of $287\frac{J}{kg \cdot K}$, and any significant deviations are noted. The success criteria for this test is the condition that no deviations are present of sufficient magnitude to be judged by the SME to be problematic.

9.4 Wind Speed Reconstruction Test

An expression relating wind speed statistics and wind component statistics can be derived:

$$WS' = \sqrt{U^2 + V^2 + \sigma_U^2 + \sigma_V^2 - \sigma_S^2}. \qquad \text{Eq. 21}$$

For this test, RRA monthly mean values of U and V are used along with standard deviations for U, V, and WS, to compute a new wind speed estimate, WS'. WS' is then compared to the RRA monthly mean WS value for each month and altitude, and any significant deviations are noted. The success criteria for this tests is the condition that no deviations are present of sufficient magnitude to be judged by the SME to be problematic.

10.0 STEP 8: CREATE FINAL DATA PRODUCTS

Once all issues identified in validation testing are successfully addressed and a set of RRA statistics are generated that pass all validation tests, the following final data products are created: (1) an Excel spreadsheet file containing computed RRA values for all statistical parameters for all months and altitudes, (2) an Earth-GRAM formatted text file containing wind statistics, (3) an Earth-GRAM formatted text file containing thermodynamic statistics, (4) an Earth-GRAM formatted text file containing moisture statistics, and (5) a text file containing all constituent profiles used to produce the final RRA product. The GRAM-formatted files are given in Appendix I.

11.0 GRAPHICAL SUMMARY OF RESULTS

Although the formal results of the current development process are the data products described in Section 10.0, it may be useful to produce a series of graphs summarizing the analytical results. Three types of graphs are described in the following sections: diagnostic testing results, validation testing results, and output statistical parameter profiles. The graphs themselves are shown in Appendix II.

11.1 Diagnostic Testing Results

Diagnostic testing is performed analytically, but it is worthwhile to generate profile overlay plots of the test variables. Recalling that diagnostic testing was performed on WS, U, V, P, T, and Td, the respective results are shown in Figures 1-6. Each figure contains 12 monthly graphs for a specific variable. Each graph shows all constituent monthly profiles. In addition to the individual profiles (shown in solid pale blue lines), the mean profile (solid red line), the $\mu \pm 2\sigma$ envelopes (red dashed lines), the $\mu \pm 3\sigma$ envelopes (red dotted lines), and the $\mu \pm 6\sigma$ envelopes (solid green lines) are shown for reference.

11.2 Validation Testing Results

Ten individual validation tests are performed. These include skewness limits tests for WS, T, Td, P, and D, the three Buell relation tests, the gas law reconstruction test, and the wind speed reconstruction test. Results of these tests are shown, respectively, in Figures 7-16.

11.3 Statistical Parameter Profiles

As described in Section 1.4, profile values are computed for 42 statistical quantities. Graphs of these are shown below in the order listed in Table 1. Each quantity has two associated plots. The first plot is a composite of 12 monthly profiles. The second plot is the annual profile. Together, these graphs are shown in Figures 17-92.