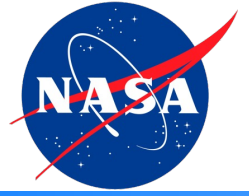

National Aeronautics and Space Administration

Construction of a Range Reference Atmosphere (RRA) for Woomera, Australia

Corey Walker

Jacobs Space Exploration Group

MSFC Natural Environments Branch

Contract Number: 80MSFC18C0011

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May 7-9, 2024

What is a RRA?

- Comprehensive Atmospheric Profile:

  A RRA dataset provides a detailed profile of atmospheric conditions, including temperature, pressure, density, humidity, wind speed, and direction, for a range of altitudes over a specific geographical location.

- Standardized Representation:

  An RRA serves as a standardized representation of typical atmospheric conditions (mean value and some measures of variability) encountered within a specific region.

Source [2]

REFERENCE AND STANDARD ATMOSPHERE MODELS

Dale L. Johnson* and Barry C. Roberts
NASA Marshall Space Flight Center, Huntsville, Alabama 35812

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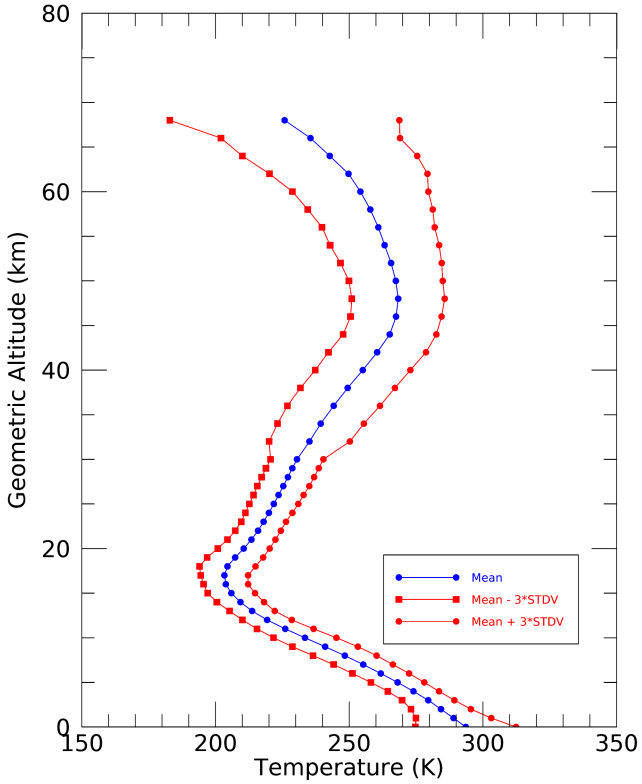
University of Alabama in Huntsville, Huntsville, Alabama 35899

Source [1]



Source: 1983 CCAFS RRA, Annual table

Table 2. Listing of Published IRIG & RCC Range Reference Atmospheres.

1.	Argentia, New Foundland
2.	Ascension Island, South Atlantic
3.	Barking Sands, Hawaii
4.	Cape Canaveral, Florida
5.	China Lake, California
6.	Dugway Proving Ground, Utah
7.	Edwards AFB, California
8.	Eglin AFB, Florida
9.	Eniwetok, Marshall Islands, Pacific
10.	Fairbanks, Alaska
11.	Fort Churchill, Canada
12.	Fort Greeley, Alaska
13.	Fort Huachuca, Arizona
14.	Johnston Island, Pacific
15.	Kodiak, Alaska
16.	Kwajalein, Marshall Islands, Pacific
17.	Lihue Kauai, Hawaii
18.	Nellis AFB, Nevada
19.	Point Arguello, California
20.	Point Mugu, California
21.	Roosevelt Roads, Puerto Rico
22.	Shemya, Alaska
23.	Taguac, Guam, Pacific
24.	Thule, Greenland
25.	Vandenberg AFB, California
26.	Wake Island Pacific
27.	Wallops Island, Virginia
28.	White Sands, New Mexico
29.	Yuma PG, Arizona

Some Background on RRAs

- RRAs have undergone several iterations since their inception in the 1960s, with updates in 1983, 2006, 2013, and 2019.
- The MSFC Natural Environments Branch (EV44) generated the 2013 and 2019 RRA datasets.
- The Range Commanders Council Meteorology Group aims to periodically update RRAs to maintain accurate representations of the upper atmosphere at selected ranges of interest.
- EV44 is uniquely positioned to provide this support given previous efforts to establish a development and update methodology.

From **Range Reference Atmosphere 2019**, JPID-FY19-001801

Source [1]

Table 2 Sites Selected for RRA 2019 Production

Sites for RRA 2019	Abbreviation
Edwards Air Force Base, CA	EAFB
Vandenberg Air Force Base, CA	VAFB
Yuma Proving Grounds, AZ	YPG
Dugway Proving Grounds, UT	DPG
Naval Air Station Point Mugu, CA	MUGU
Naval Air Weapons Station China Lake, CA	CHLK
Pacific Missle Research Facility, HI	PMRF
Reagan Test Site, Kwajalein, Marshall Islands	KWAJ
Wallops Flight Facility, VA	WFF
White Sands Missle Range, NM	WSMR
Cape Canaveral Air Force Station, FL	CCAFS

Integrated Python code developed in 2020

Source [3]

Python Code Files

Filename	Description
buell.py	Functions for the Buell relationship tests
config.py	Setup environment variables for paths to data files
derived.py	Functions that compute derived quantities
diagnostics.py	Functions responsible for diagnostic tests
gaslaw.py	Functions for gas law reconstruction test
interpol.py	Functions for the interpolation step
main.py	Main entry into the RRA code package
output.py	Functions that create the final data products
qc.py	Functions for the quality control step
sites.py	Site information for input profile data
skewness.py	Functions for skewness tests
stats.py	Functions that calculate the statistics
utility.py	common functions to each step
validation.py	Functions for the validation step
version.py	Version of this code
wscomp.py	Functions for wind speed reconstruction tests
rra.py	Command line code for running RRA

Need for a Woomera RRA

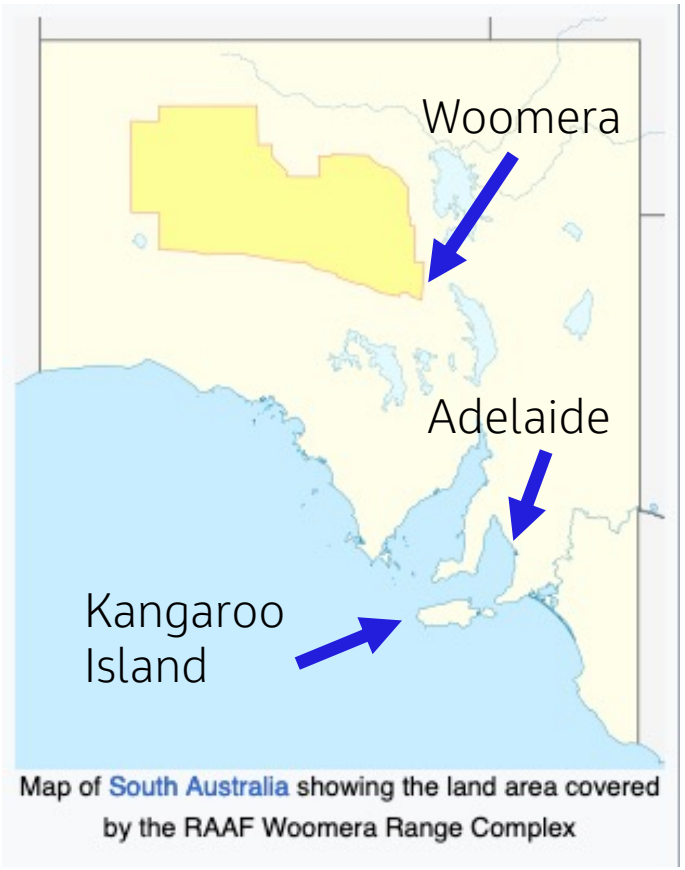
- Natural Environments received multiple requests from the Range and Aerospace meteorology community for a Woomera RRA.
- NASA and US defense programs have used Australian Outback for rocketry and upper atmosphere research.
- Woomera RRA would serve as dataset to assist in future Woomera launch applications.
- In near future, the RRA will be available on AFRC Weather website:

https://weather.dfrc.nasa.gov/Climatology

Source [4] LICENSE [1]

Launch of a NASA Skylark sounding rocket from the Woomera Range Complex in c. 1961

Source [4] LICENSE [2]



Map of South Australia showing the land area covered by the RAAF Woomera Range Complex

1961 September 18 - . 12:15 GMT - . *Launch Site*: Woomera. *Launch Complex*: Woomera LA2. *Launch Pad*: LA2 SL. *Launch Vehicle*: Skylark.

- **Southern Sky Survey Ultraviolet Astronomy mission** - . *Nation*: USA. *Agency*: NASA. *Apogee*: 193 km (119 mi). First of four scheduled Skylark rocket firings was launched from Woomera in the joint United States-Australian ultraviolet survey of the southern skies..

Method

STEP 1: DEFINE/OBTAIN/INITIALIZE INPUT DATA

SITE ID	DATA	RECORD	Number of Input Profiles
WOOM, WMO ID 94659 located at 31.14609S, 186.805E	Integrated Global Radiosonde Archive (IGRA) which is a product of the National Center for Environmental Information	1990 - 2023	19,384 atmospheric profiles

Meteorological Parameter	Units	Statistical Quantities
Geometric altitude (Z)	km	Vertical coordinate (independent variable)
Zonal wind component (U)	m/s	Mean, median, standard deviation
Meridional wind component (V)	m/s	Mean, median, standard deviation
Wind component correlation (R_{UV})	dimensionless	Linear product-moment correlation coefficient
Wind speed (WS)	m/s	Mean, median, standard deviation, skewness
Number of wind observations	dimensionless	Arithmetic sum
Atmospheric pressure (P)	mb	Mean, median, standard deviation, skewness
Atmospheric temperature (T)	C	Mean, median, standard deviation, skewness
Atmospheric density (D)	g/m^3	Mean, median, standard deviation, skewness
Number of thermodynamic observations	dimensionless	Arithmetic sum
Water vapor pressure (VP)	mb	Mean, median, standard deviation, skewness
Virtual temperature (Tv)	C	Mean, median, standard deviation, skewness
Dewpoint temperature (Td)	C	Mean, median, standard deviation, skewness
Number of humidity observations	dimensionless	Arithmetic sum

STEP 2: PERFORM QUALITY CONTROL

1. Tolerance Checks

		Out-of-Bounds Value Limits	
Parameter	**Units**	**Lower Limit**	**Upper Limit**
WD	Degrees, clockwise from North	WD < 0	WD > 360
WS	m/s	WS < 0.0	WS > 200.0
T	C	T < -100	T > 70.0
Td	C	Td < -100	Td > 70.0
P	mb	P < 0.0	P > 1200.0

2. **Surface Level Check**

- Make sure profile is within 0.1 km of nominal surface elevation (169 m above Mean Sea Level).

3. **Duplicate Profile Check**

- Remove 1000 ft resolution profile if you have a duplicate 100 ft profile.

4. **Missing Data Check**

- Replace -999.99 values with NaN.

5. **Minimum Data Levels Check ***

- Must have at least 5 measurements in profile.

6. **Maximum Data Gap Interval Check ***

- If profile has a gap between adjacent levels above 5km, it is removed.

7. **Wind Speed Shear Check**

- Maximum wind shear limit is established with a value of 0.3 s^{-1}

8. **Negative Altitude Change Adjacent Levels Check**

- Corrupt data, in which altitude is reported incorrectly

9. **Visual Inspection Check**

- profiles are noted as suspect based on assorted computational anomalies

* Denotes that step is performed independently for WS, T, Td, and P

STEP 3: INTERPOLATION STEP

1. **Establish Output Altitude Grid**
- Z is established covering the vertical domain from surface to 30 km with a 0.5 km vertical resolution.

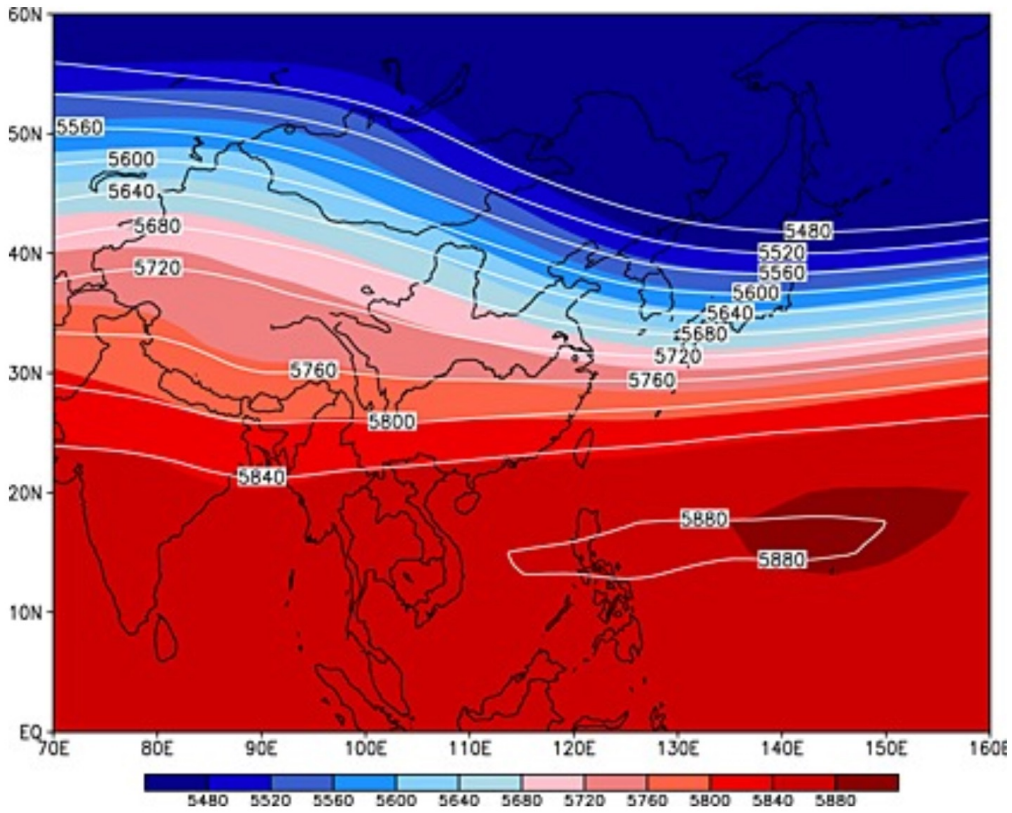
2. **Compute Geopotential Heights for Output Altitude Grid**
- Create an array of Geopotential heights for each geometric height.
- Geopotential heights help approximate where pressure levels should exist in relation to altitude.
- The location of a pressure measurement in relation to geometric height will change based on gravitational acceleration differences, centrifugal force, the ellipsoidal shape of the Earth and latitude.

3. **Compute Wind Components**

$$U = -WS \times \sin(WD)$$
$$V = -WS \times \cos(WD)$$

4. **Interpolate**
- Define upper and lower limits of geometric height for U, V, WS, T, Td in relation to geopotential heights.

Source [5]



Geopotential height (unit: gpm) at 500 hPa of this spring (shaded) and the climatic mean of the springs from 1981 to 2010 (contour).

STEP 4: COMPUTE DERIVED QUANTITIES

Once all profiles of WS, U, V, T, Td, and P have been interpolated to the output grid resolution, additional derived quantities of VP, Tv, and D are computed

1. **Compute Vapor Pressure ***

$$\mathrm{VP_{OUT}} = 6.112 \times 10^{\left[\frac{17.67 \times TdC}{(TdC+243.5)}\right]}$$

2. Compute Water Mixing Ratio

- 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

$$w = \epsilon \times \frac{VP}{P-VP}$$

3. Compute Virtual Temperature

$$\mathrm{TV_{OUT}} = T \times \frac{1+\frac{w}{\epsilon}}{1+w}$$

4. Compute Density

$$\mathrm{D_{OUT}} = 348.36787 \times \frac{P_{OUT}}{Tv_{OUT}}$$

Will not be calculated above the first level where T < -60 C.

- We saw this value on average at ~12-15 km

Question:

- How do you get densities in the upper atmosphere?
- VP → 0, so w → 0 and TV → T

STEP 5: COMPUTE STATISTICS

- Segregate data by month and altitude
- Compute Mean, Median, and Standard Deviations for the variables WS, U, V, P, T, D, VP, Tv, and Td.
- Compute Skewness, a measure of the median values compared to the mean to look for bias.

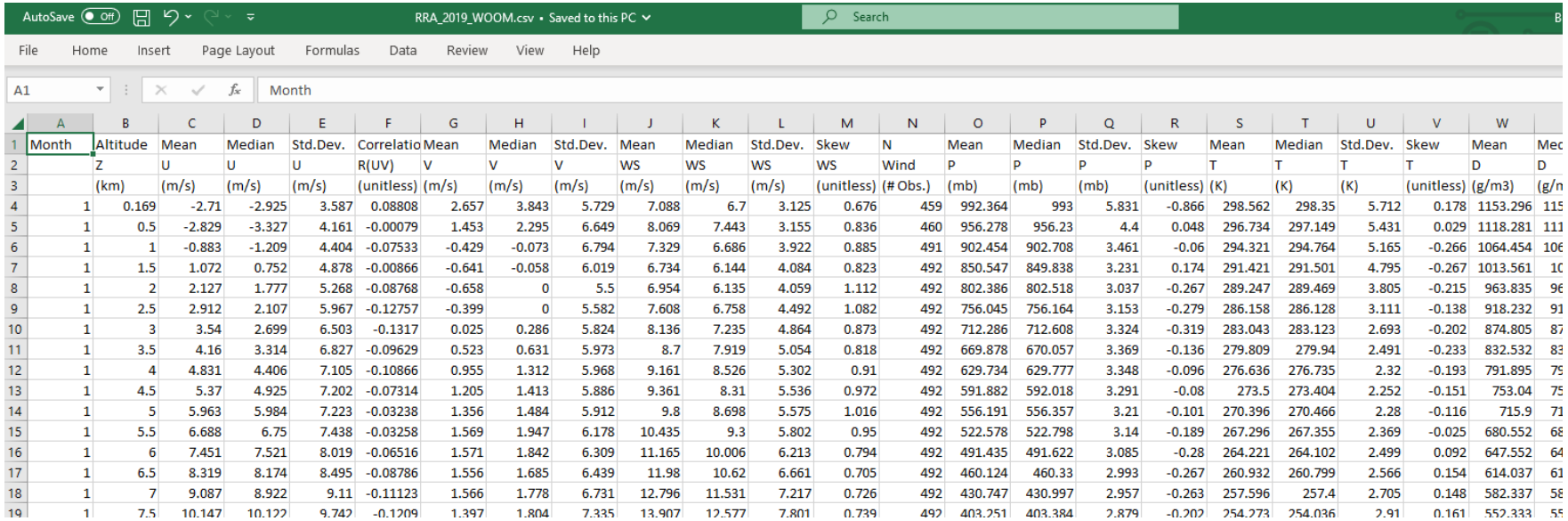
STEP 6: PERFORM DIAGNOSTICS

- Values are tested to see if any exceed the mean +/- 6 standard deviation envelopes for WS, U, V, T, P, and Td.
- Values above and below 6 standard deviations are flagged for removal.
- Steps 5 and 6 iterate until there are no values above and below 6 standard deviations.

STEP 7: PERFORM VALIDATION TESTING

- Skewness coefficients of WS, T, P, Td, and D are evaluated to ensure they don't exceed specified limits.
- *Buell Test* is applied to maintain equality between terms based on P, T, and D statistics and significant deviations are noted.
- *Gas Law Reconstruction Test* is used to compute gas constant from monthly mean values, and these are compared to accepted value; significant deviations noted.
- *Wind Speed Reconstruction Test* is used to estimate wind speed from wind component statistics, compares to computed mean wind speed; significant deviations noted.

STEP 8: OUTPUT DATA

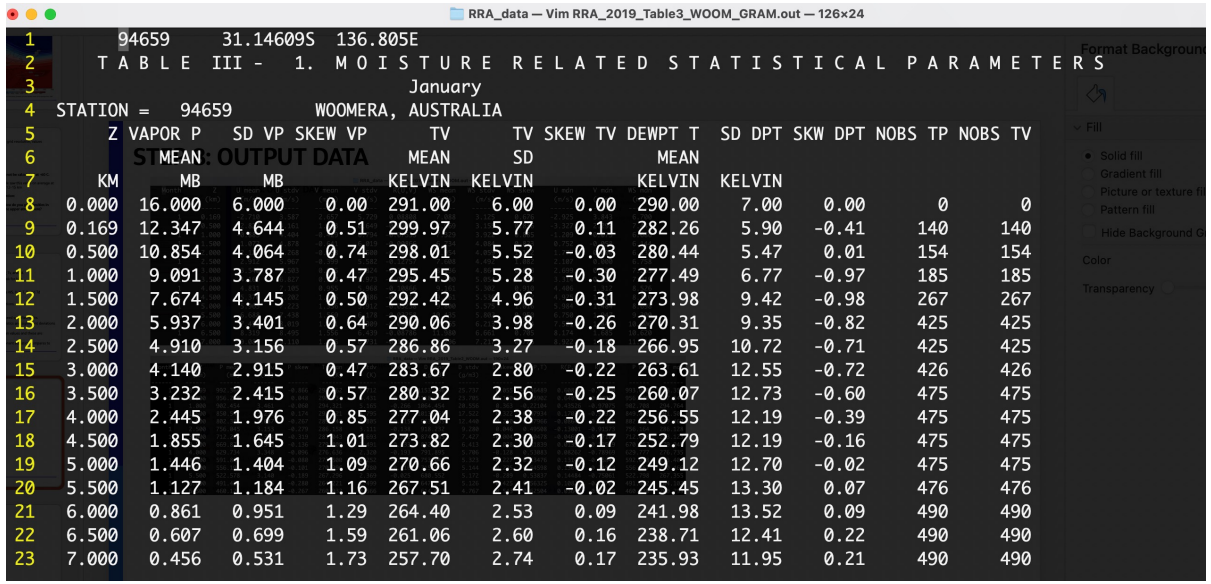


AutoSave Off — RRA_2019_WOOM.csv • Saved to this PC — Search

File Home Insert Page Layout Formulas Data Review View Help

A1 — Month

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	
1	Month	Altitude	Mean	Median	Std.Dev.	Correlatio	Mean	Median	Std.Dev.	Mean	Median	Std.Dev.	Skew	N	Mean	Median	Std.Dev.	Skew	Mean	Median	Std.Dev.	Skew	Mean	Mec
2		Z	U	U	U	R(UV)	V	V	V	WS	WS	WS	WS	Wind	P	P	P	P	T	T	T	T	D	D
3		(km)	(m/s)	(m/s)	(m/s)	(unitless)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(unitless)	(# Obs.)	(mb)	(mb)	(mb)	(unitless)	(K)	(K)	(K)	(unitless)	(g/m3)	(g/n
4	1	0.169	-2.71	-2.925	3.587	0.08808	2.657	3.843	5.729	7.088	6.7	3.125	0.676	459	992.364	993	5.831	-0.866	298.562	298.35	5.712	0.178	1153.296	115
5	1	0.5	-2.829	-3.327	4.161	-0.00079	1.453	2.295	6.649	8.069	7.443	3.155	0.836	460	956.278	956.23	4.4	0.048	296.734	297.149	5.431	0.029	1118.281	111
6	1	1	-0.883	-1.209	4.404	-0.07533	-0.429	-0.073	6.794	7.329	6.686	3.922	0.885	491	902.454	902.708	3.461	-0.06	294.321	294.764	5.165	-0.266	1064.454	106
7	1	1.5	1.072	0.752	4.878	-0.00866	-0.641	-0.058	6.019	6.734	6.144	4.084	0.823	492	850.547	849.838	3.231	0.174	291.421	291.501	4.795	-0.267	1013.561	10
8	1	2	2.127	1.777	5.268	-0.08768	-0.658	0	5.5	6.954	6.135	4.059	1.112	492	802.386	802.518	3.037	-0.267	289.247	289.469	3.805	-0.215	963.835	96
9	1	2.5	2.912	2.107	5.967	-0.12757	-0.399	0	5.582	7.608	6.758	4.492	1.082	492	756.045	756.164	3.153	-0.279	286.158	286.128	3.111	-0.138	918.232	91
10	1	3	3.54	2.699	6.503	-0.1317	0.025	0.286	5.824	8.136	7.235	4.864	0.873	492	712.286	712.608	3.324	-0.319	283.043	283.123	2.693	-0.202	874.805	87
11	1	3.5	4.16	3.314	6.827	-0.09629	0.523	0.631	5.973	8.7	7.919	5.054	0.818	492	669.878	670.057	3.369	-0.136	279.809	279.94	2.491	-0.233	832.532	83
12	1	4	4.831	4.406	7.105	-0.10866	0.955	1.312	5.968	9.161	8.526	5.302	0.91	492	629.734	629.777	3.348	-0.096	276.636	276.735	2.32	-0.193	791.895	79
13	1	4.5	5.37	4.925	7.202	-0.07314	1.205	1.413	5.886	9.361	8.31	5.536	0.972	492	591.882	592.018	3.291	-0.08	273.5	273.404	2.252	-0.151	753.04	75
14	1	5	5.963	5.984	7.223	-0.03238	1.356	1.484	5.912	9.8	8.698	5.575	1.016	492	556.191	556.357	3.21	-0.101	270.396	270.466	2.28	-0.116	715.9	71
15	1	5.5	6.688	6.75	7.438	-0.03258	1.569	1.947	6.178	10.435	9.3	5.802	0.95	492	522.578	522.798	3.14	-0.189	267.296	267.355	2.369	-0.025	680.552	68
16	1	6	7.451	7.521	8.019	-0.06516	1.571	1.842	6.309	11.165	10.006	6.213	0.794	492	491.435	491.622	3.085	-0.28	264.221	264.102	2.499	0.092	647.552	64
17	1	6.5	8.319	8.174	8.495	-0.08786	1.556	1.685	6.439	11.98	10.62	6.661	0.705	492	460.124	460.33	2.993	-0.267	260.932	260.799	2.566	0.154	614.037	61
18	1	7	9.087	8.922	9.11	-0.11123	1.566	1.778	6.731	12.796	11.531	7.217	0.726	492	430.747	430.997	2.957	-0.263	257.596	257.4	2.705	0.148	582.337	58
19	1	7.5	10.147	10.122	9.742	-0.1209	1.397	1.804	7.335	13.907	12.577	7.801	0.739	492	403.251	403.384	2.879	-0.202	254.273	254.036	2.91	0.161	552.333	55



RRA_data — Vim RRA_2019_Table3_WOOM_GRAM.out — 126×24

```
      94659     31.14609S  136.805E
   T A B L E  III -  1.  M O I S T U R E  R E L A T E D  S T A T I S T I C A L  P A R A M E T E R S
                              January
STATION =   94659        WOOMERA, AUSTRALIA
      Z VAPOR P    SD VP SKEW VP       TV       TV SKEW TV DEWPT T   SD DPT SKW DPT NOBS TP NOBS TV
                                    MEAN       SD             MEAN
     KM       MB       MB                KELVIN   KELVIN            KELVIN   KELVIN
  0.000   16.000    6.000    0.00   291.00     6.00     0.00   290.00     7.00    0.00        0        0
  0.169   12.347    4.644    0.51   299.97     5.77     0.11   282.26     5.90   -0.41      140      140
  0.500   10.854    4.064    0.74   298.01     5.52    -0.03   280.44     5.47    0.01      154      154
  1.000    9.091    3.787    0.47   295.45     5.28    -0.30   277.49     6.77   -0.97      185      185
  1.500    7.674    4.145    0.50   292.42     4.96    -0.31   273.98     9.42   -0.98      267      267
  2.000    5.937    3.401    0.64   290.06     3.98    -0.26   270.31     9.35   -0.82      425      425
  2.500    4.910    3.156    0.57   286.86     3.27    -0.18   266.95    10.72   -0.71      425      425
  3.000    4.140    2.915    0.47   283.67     2.80    -0.22   263.61    12.55   -0.72      426      426
  3.500    3.232    2.415    0.57   280.32     2.56    -0.25   260.07    12.73   -0.60      475      475
  4.000    2.445    1.976    0.85   277.04     2.38    -0.22   256.55    12.19   -0.39      475      475
  4.500    1.855    1.645    1.01   273.82     2.30    -0.17   252.79    12.19   -0.16      475      475
  5.000    1.446    1.404    1.09   270.66     2.32    -0.12   249.12    12.70   -0.02      475      475
  5.500    1.127    1.184    1.16   267.51     2.41    -0.02   245.45    13.30    0.07      476      476
  6.000    0.861    0.951    1.29   264.40     2.53     0.09   241.98    13.52    0.09      490      490
  6.500    0.607    0.699    1.59   261.06     2.60     0.16   238.71    12.41    0.22      490      490
  7.000    0.456    0.531    1.73   257.70     2.74     0.17   235.93    11.95    0.21      490      490
```

Primary product

- CSV Excel file with all computed RRA values

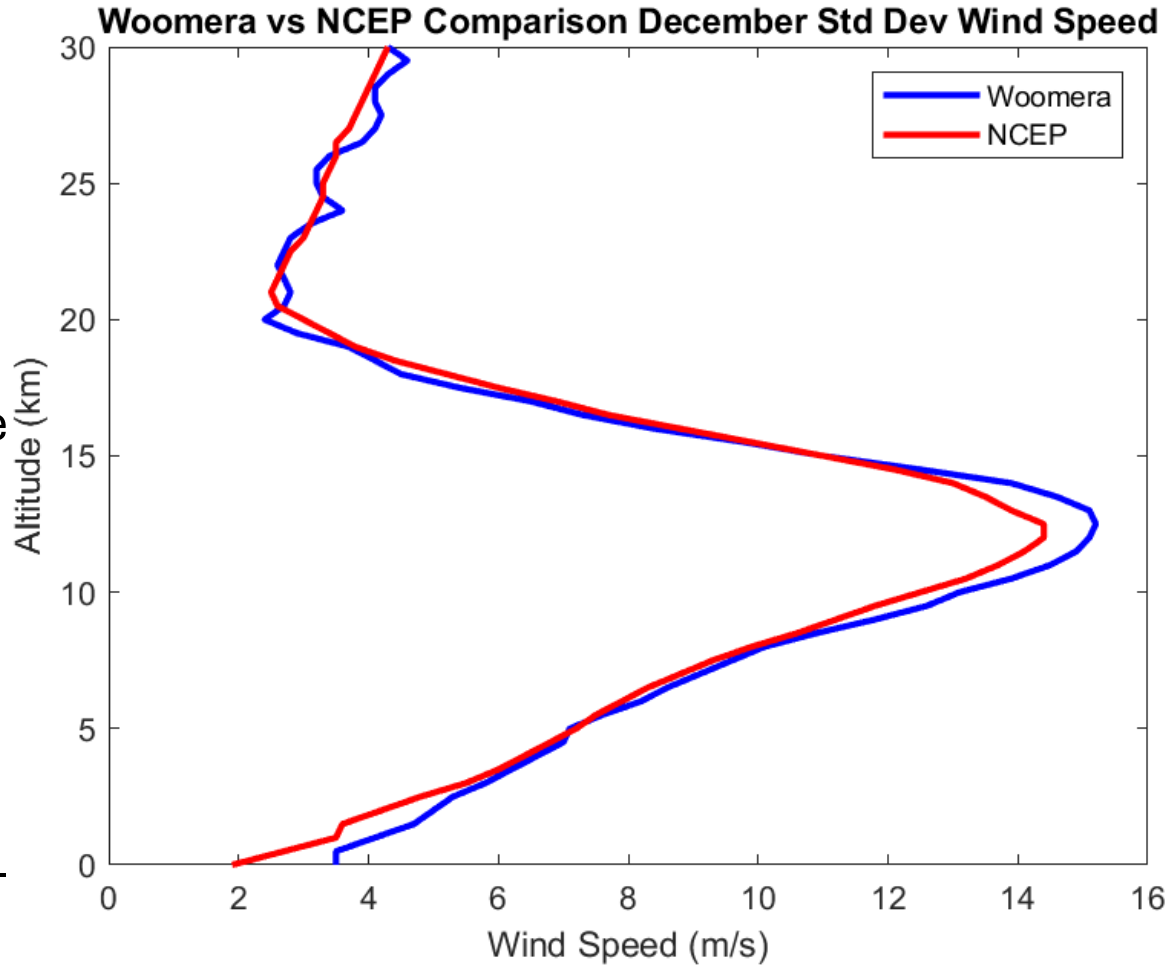
Global Reference Atmosphere Model (GRAM)

- Formatted Text file for wind statistics
- Formatted Text file for thermodynamics
- Formatted Text file for moisture values

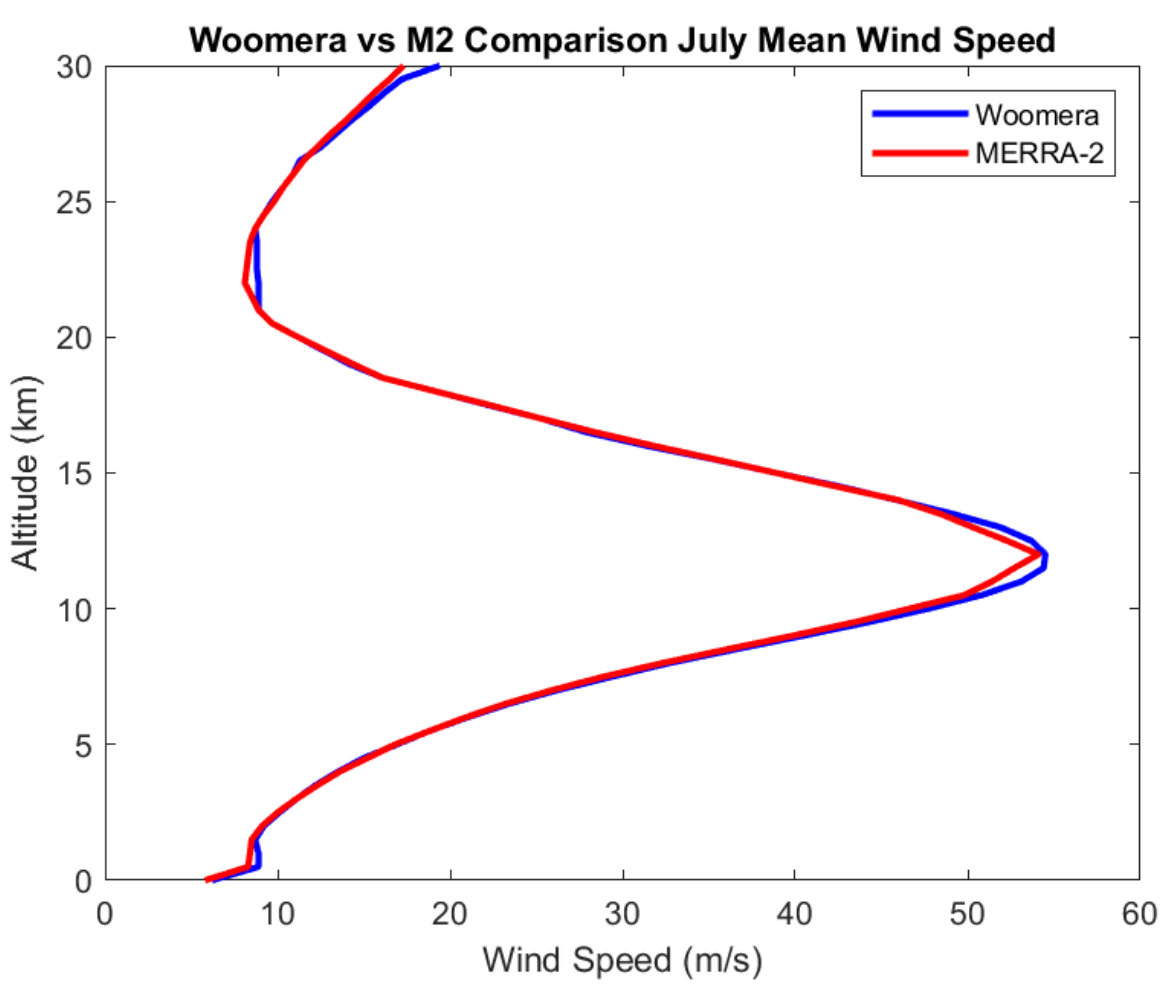
Additional Validation Examples

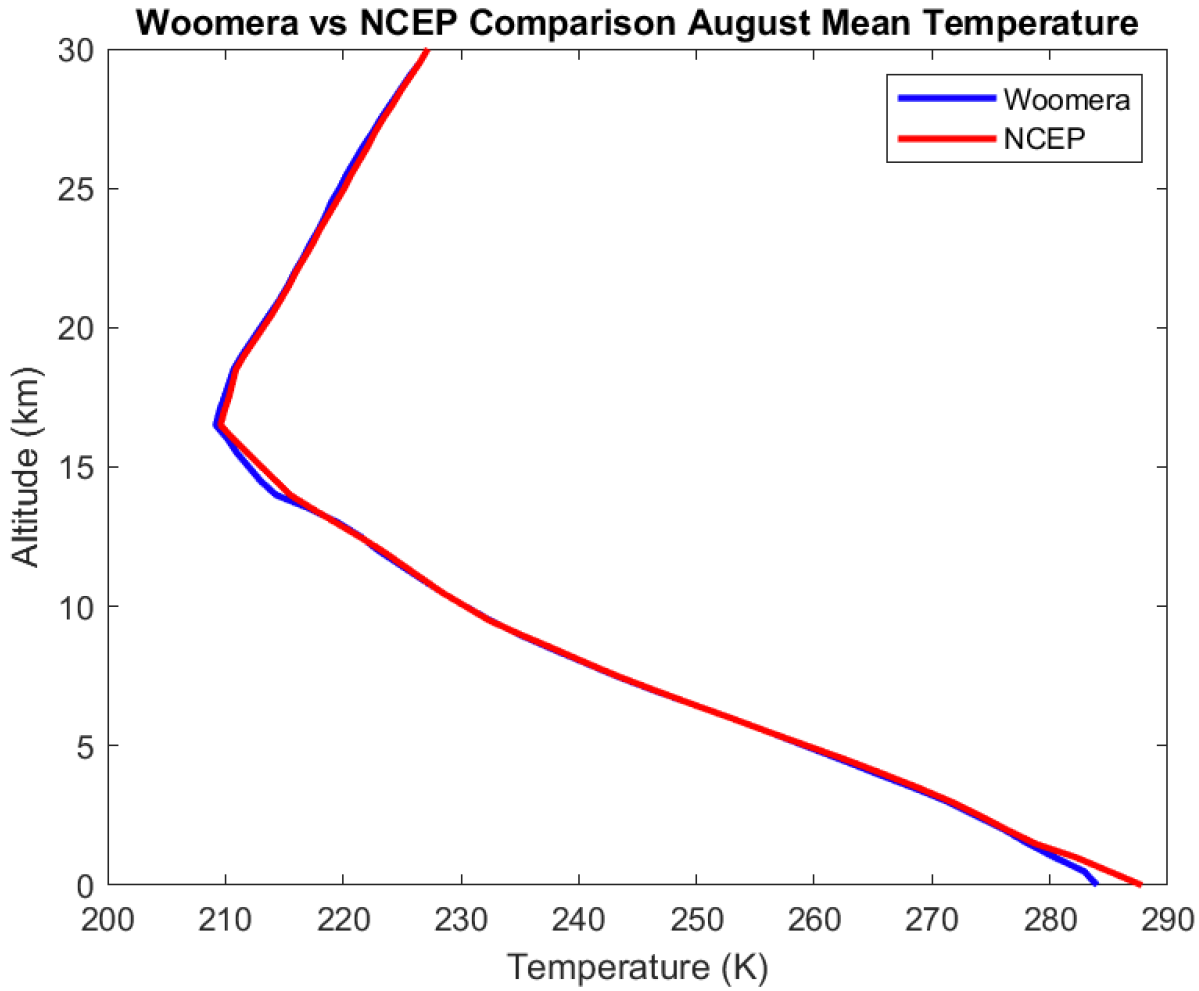
Number of Input Profiles	Number of Output Profiles
19,384	8,398

- The process defined in the prior steps reduced the number of usable profiles from 19,384 to 8,398.
- Validation of the RRA was conducted through comparison between the RRA and Earth-GRAM outputs.
- Earth-GRAM data used for comparison was generated utilizing the National Centers for Environmental Prediction (NCEP) and the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) data option in Earth-GRAM



More Validation Examples





How can users get the data / RRA service?

- The Woomera RRA will be released in the Spring 2024 GRAM Suite release.
  - GRAM Suite is available through the NASA Software Catalog: https://software.nasa.gov/software/MFS-33888-1
- Contact Earth-GRAM Lead Patrick White regarding requests for RRA development or upgrades:
  - Email: patrick.w.white@nasa.gov
- There will be periodic updates to RRAs.

Sources

- [1] Burns, Lee. 2019. Range Reference Atmosphere 2019. Accessed 1 23, 2024. https://weather.dfrc.nasa.gov/data/rcc/RRA_2019_Dev_Report.pdf.
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- [4] Wikipedia contributors. (2024, February 26). RAAF Woomera Range Complex. In *Wikipedia, The Free Encyclopedia*. Retrieved 14:13, April 8, 2024, from https://en.wikipedia.org/w/index.php?title=RAAF_Woomera_Range_Complex&oldid=1210306705,
- [5] Lu, Er & Liu, Siyuan & Luo, Yali & Zhao, Wei & Li, Hui & Chen, Hongxing & Zeng, Yingting & Liu, Peng & Wang, Xiaomin & Higgins, Wayne & Halpert, Mike. (2014). The atmospheric anomalies associated with the drought over the Yangtze River basin during spring 2011. Journal of Geophysical Research: Atmospheres. 119. 10.1002/2014JD021558. Used with permission from author. Also see https://www.agu.org/publish-with-agu/publish/agu-publications-policies. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014JD021558

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- [2] The map came from https://commons.wikimedia.org/wiki/File:Woomera_Test_Range_map.svg and is licensed for use under CC BY-SA 3.0, which can be found at https://creativecommons.org/licenses/by-sa/3.0/deed.en. Geographic labels with arrow indications were added.