Range Reference Atmosphere 2013 Production Methodology

Lee Burns
Raytheon/Jacobs ESSSA
NASA/MSFC/EV44 Natural Environments

Spring, 2015 RCC-MG Meeting

JACOBS ESSSA Group

Philosophy, Ground Rules, and Assumptions

Why did NASA/MSFC/EV44 (EV44) take on this project?

- General support for RCC programs and products.
- Use in Earth Global Reference Atmospheric Model (Earth-GRAM).

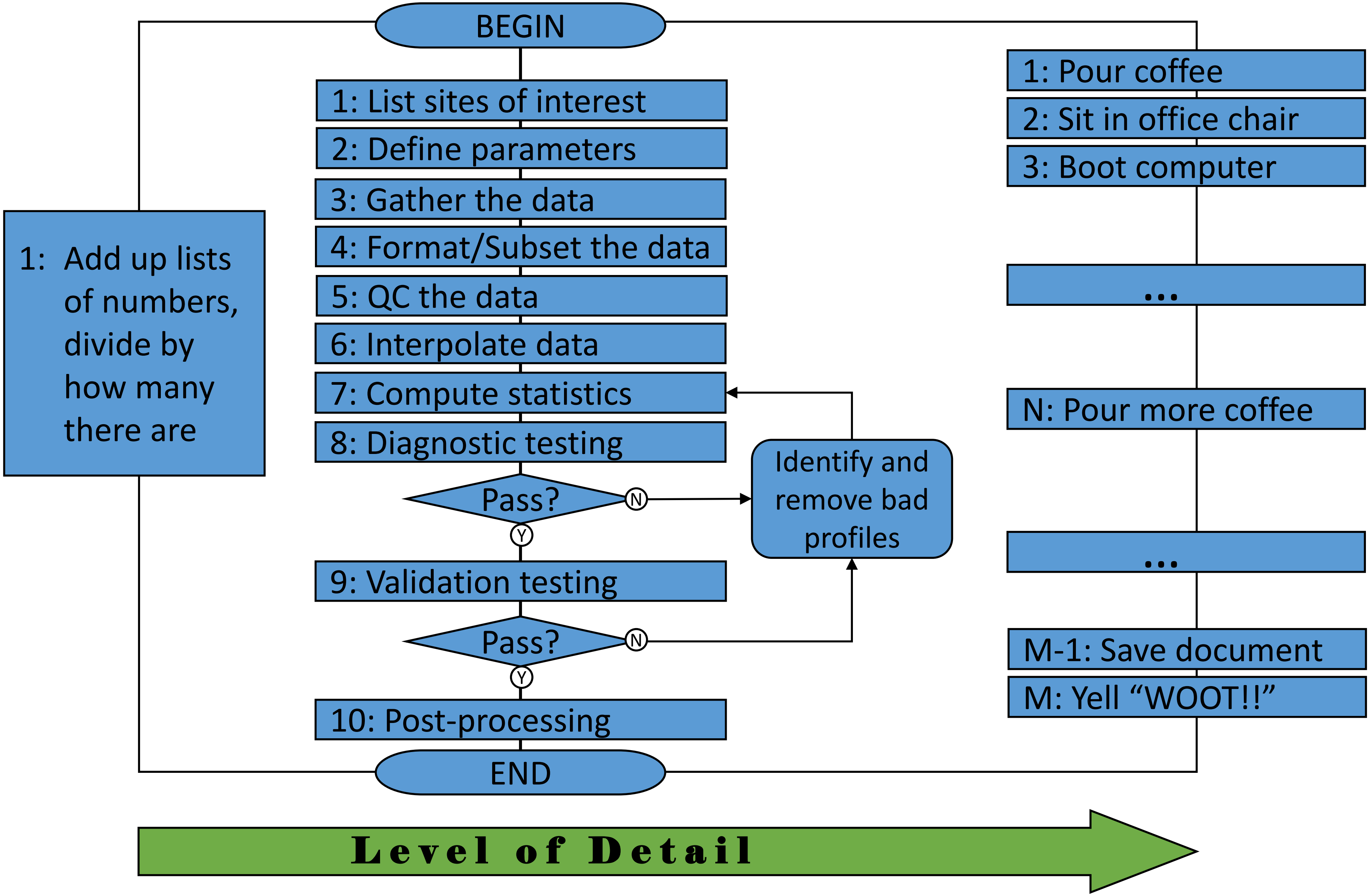
Data quality is stressed over quantity.

- If a profile fails a quality control (QC) check for one parameter then that profile is removed from computations for all parameters.
- Some QC relies on subject matter expertise (SME). Subjective judgments emphasize conservatism. "If in doubt, throw it out."

Process is performed in discrete steps.

- Output results from each step are saved in separate data files. This allows intermediate process inspection. Outputs from one step are used as the inputs to the next step.
- A lofty goal is full automation, but the difficulties associated with "real data" require SME interaction and babysitting.

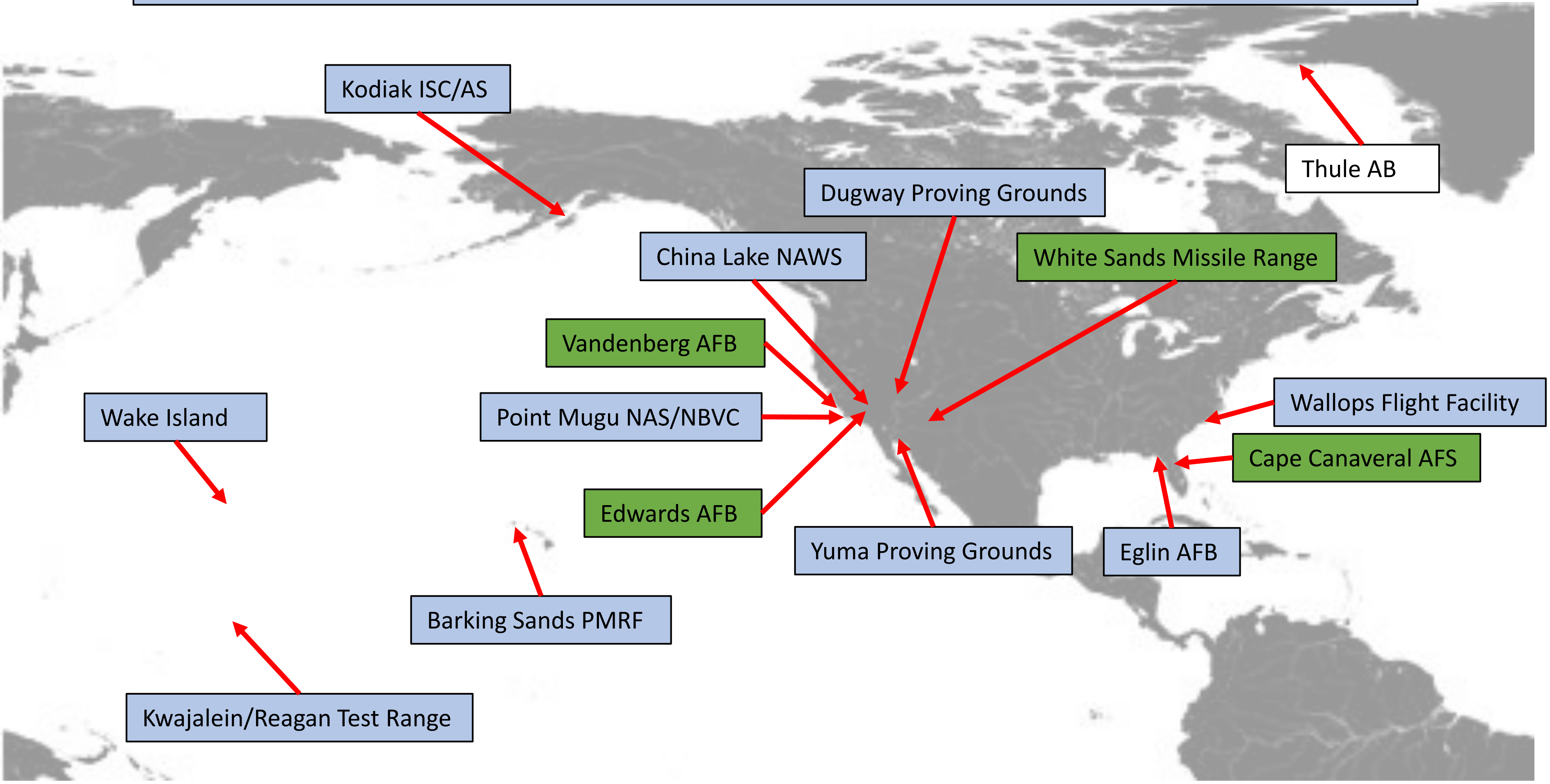
Possible Methodology Outlines



Step 1: Determine Sites of Interest

Phase 1: Funded by NASA Space Launch System program.

Phase 2: Funded by Range Commanders Council.



Step 2: Define Parameters

Vertical coordinate:

Geometrical altitude in meters above Mean Sea Level.

Physical variables

Wind speed:	WS	Virtual temperature:	Tv
Zonal wind:	U	Pressure:	P
Meridional wind:	V	Density:	D
Temperature:	T	Vapor pressure:	VP
Dewpoint:	Td		

Statistical quantities

Mean value:	μ	Skewness coefficient:	SKEW
Median value:	MDN	Linear correlation:	$r_{x,y}$
Standard deviation:	σ		

Step 3: Gather the Data

First preference: Get data directly from range weather office.

Cape Canaveral	Vandenberg
Edwards	Wallops
Wake Island	China Lake

Second preference: Get data from archival/distribution site.

National Climatic Data Center (NCDC), Integrated Global Radiosonde Archive (IGRA)

Kwajalein	Wake Island
Dugway	Barking Sands
Eglin	Thule
Kodiak	Yuma
Wallops	China Lake
Vandenberg	Point Mugu

Earth System Research Laboratory (ESRL)

Yuma	Point Mugu
China Lake	

Step 4: Format/Subset the Data

NASA/MSFC/EV44 has a standard format for archiving data.

- Master File Format (MFF)
- Various input formats (Shuttle, IGRA, ESRL) are converted to MFF.
- Remove ‘garbled’ and duplicate profiles identified during data ingest.
- Convert year values from 2-digit to 4-digit, if necessary.
- Convert various “missing data” flags (ex. -999.99) to IEEE NaNs.
- Compute U and V winds from wind speed and direction.
- Input datasets with long periods of record (POR) are trimmed to highlight most recent data (highest quality, most representative). Standard POR is from 1990 to present. If sample sizes are insufficient, then older data are included.
- Multiple-source input data are integrated into a single file.

JACOBS ESSSA Group

Step 5: Quality Control the Data

Out of bounds value check. Convert the following to NaNs:

- U or V values > 200 m/s.
- T values < -100 C
- T values > 70 C.
- Td values where T < -60 C.
- Td value < -60 C.
- P value < 0 mb
- P value > 1200 mb.

Remove profiles for the following conditions:

- Lowest reporting altitude has no valid data (NaNs).
- # levels with any valid data < 10.
- # levels with valid P, T, Td, U, or V data < 8.
- Lowest reporting altitude > nominal surface + 0.1 km.
- Minimum height between adjacent valid data altitudes > 5 km.
- Maximum wind shear between adjacent levels > 0.3 s^{-1}.
- Profile is judged to be erroneous by visual inspection by SME. This is an explicitly interactive process.

Step 6: Interpolate the Data

All individual profiles are interpolated to a common grid.

6.1: Establish output altitude grid.

6.2: Compute geopotential heights for output grid.

6.3: Interpolate wind values to output grid.

6.4: Interpolate pressure to output grid.

6.5: Interpolate temperature, dewpoint to output grid.

6.6: Compute derived quantities.

Step 6.1: Establish Output Altitude Grid

- Standard vertical domain goes from 0-30 km MSL.
- 0.5 km vertical resolution.
- Lowest grid value is set to nominal surface value.
- Any altitudes < nominal surface value are removed.

Step 6.2: Compute Geopotentials

Compute latitude-dependent surface gravity.

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

Compute vertical derivative of gravity.

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

Compute effective Earth radius.

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

Compute geopotential heights.

$$H_z = \frac{g_\phi}{g_0} \times R_{EFF} \times \frac{Z}{R_{EFF} + Z}$$

Resulting output grid geopotential heights are named H_{out}.

Step 6.3: Interpolate Wind Values

Compute geopotential heights for input grid wind data.

Same procedure as in 6.2. These values are named H_{in}.

For each N^{th} output geopotential grid value, $H_{out,N}$, find nearest bounding upper and lower input grid geopotential values.

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

Find input grid indices for bounding geopotential heights and note bounding wind values.

I_A, I_B such that: $H_{in}(I_A) = H_A$. $H_{in}(I_B) = H_B$. Then,
$WS_A = WS(I_A)$, $U_A = U(I_A)$, $V_A = V(I_A)$.
$WS_B = WS(I_B)$, $U_B = U(I_B)$, $V_B = V(I_B)$.

Interpolate Wind values.

$$\left.\begin{aligned} WS_N &= WS_B + (WS_A - WS_B) * C_1 \\ U_N &= U_B + (U_A - U_B) * C_1 \\ V_N &= V_B + (V_A - V_B) * C_1 \end{aligned}\right\} \text{ Where } C_1 = \frac{(H_{out,N} - H_B)}{(H_A - H_B)}.$$

Step 6.4: Interpolate Pressure

Compute H_A, H_B, I_A, and I_B.

Same procedure as in 6.3.

Compute nearest lower bounding pressure.

$P_B = P(I_B)$.

Compute interval average virtual temperature.

Procedure for computing Tv shown on following slides.

$Tv_{AVE} = [Tv(I_A) + TV(I_B)] / 2$.

Interpolate pressure values.

$$P_N = P_B \times EXP\left(\frac{H_B - H_A}{29.2712617 \times Tv_{AVE}}\right).$$

Step 6.5: Interpolate Temperature, Dewpoint

Compute H_A, H_B, I_A, and I_B.

Same procedure as in 6.3.

Compute upper and lower bounding temperature and dewpoint values.

$T_A = T(I_A)$, $T_B = T(I_B)$.
$Td_A = Td(I_A)$, $Td_B = Td(I_B)$.

Interpolate temperature and dewpoint logarithmically with respect to pressure.

$$T_N = T_B + (T_A - T_B) * C_2.$$
$$Td_N = Td_B + (Td_A - Td_B) * C_2.$$

Where $C_2 = \frac{[\ln(p_N) - \ln(p_B)]}{[\ln(p_A) - \ln(p_B)]}$.

JACOBS ESSSA Group

Step 6.6: Compute Derived Quantities

Compute vapor pressure.

VP $= 6.112 \times 10^{\left[\frac{17.67 \times Td}{(Td+243.5)}\right]}$.

Compute virtual temperature.

First, define water vapor mixing ratio: $w = \epsilon \times \frac{VP}{P-VP}$. Then,

Tv $= T \times (1+w/\epsilon) \times (1 + w)^{-1}$

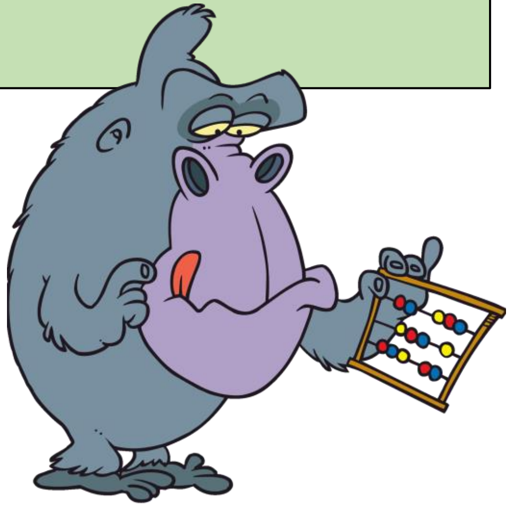
Compute density.

D = 348.36787 × P × Tv^{-1}.

Step 7: Compute Statistical Values

Computations are made independently for each altitude.
Monthly, net annual values.

• Sample size:	Wind, Thermo, Humidity.
• Mean values:	U, V, WS, P, T, D, VP, Tv, Td.
• Median values:	U, V, WS, P, T, D, VP, Tv, Td.
• Standard deviations:	U, V, WS, P, T, D, VP, Tv, Td.
• Skewness coefficients:	WS, P, T, D, VP, Tv, Td.
• Correlation coefficients:	U, V.



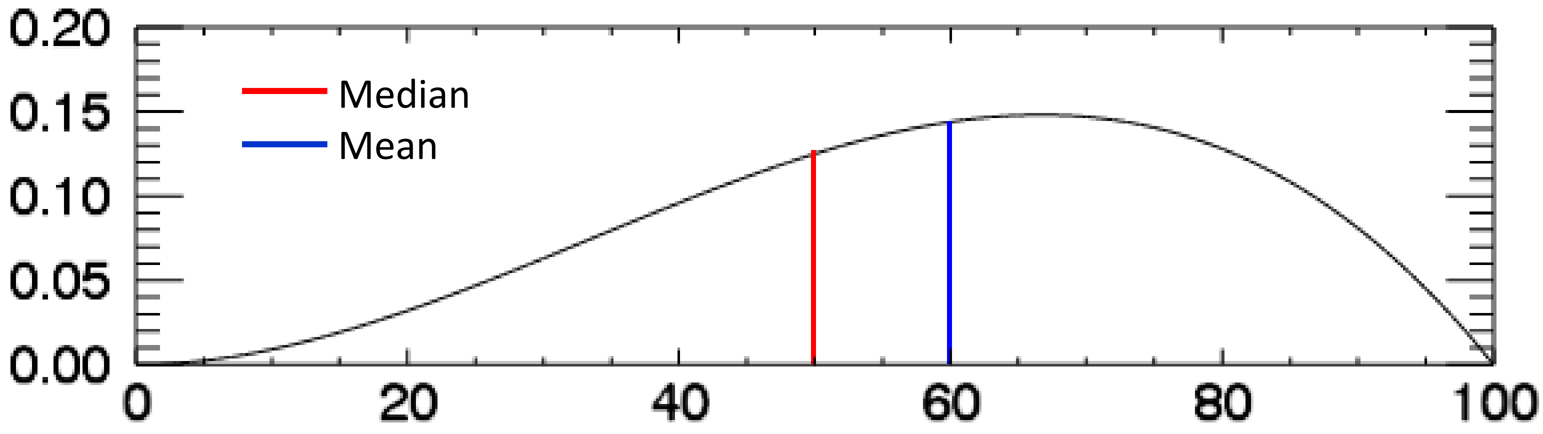
Compute Mean and Median Values

Mean values:

$\mu_X = N^{-1} \times \sum_{i=1}^{N} X_N.$

Median values:

Let $\acute{X} = sort(X).\ Then, MDN_x = \begin{cases} \acute{X}\left(\frac{N+1}{2}\right) & \text{odd N.} \\ \frac{1}{2} \times \left[\acute{X}\left(\frac{N}{2}\right) + \acute{X}\left(\frac{N}{2} + 1\right)\right] & \text{even N.} \end{cases}$



Compute Standard Deviation and Skewness

Variance:

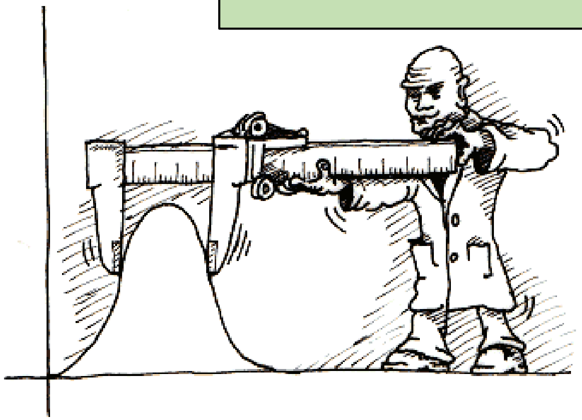
$$\mathrm{VAR}_X = \frac{1}{N-1} \times \sum_{i=1}^{N} (X_i - \mu_X)^2.$$

Standard deviations:

$$\sigma_X = \sqrt{\mathrm{VAR}_X}.$$

Skewness:

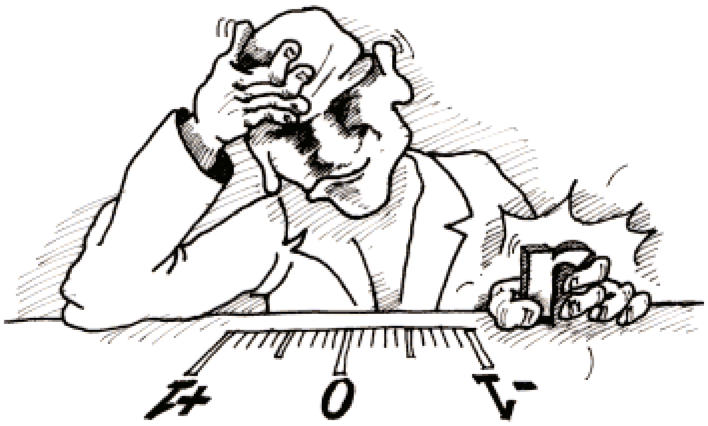
$$\mathrm{SKEW}_X = \frac{1}{N} \times \sum_{i=1}^{N} \left(\frac{X_i - \mu_X}{\sigma_X}\right)^3.$$



Compute Wind Component Correlation

Linear Pearson correlation coefficient:

$$r_{U,V} = \frac{\sum_{i=1}^{N}[(U_i - \mu_U)(V_i - \mu_V)]}{\sqrt{\sum_{i=1}^{N}(U_i - \mu_U)^2 \sum_{i=1}^{N}(V_i - \mu_V)^2}}.$$



JACOBS ESSSA Group

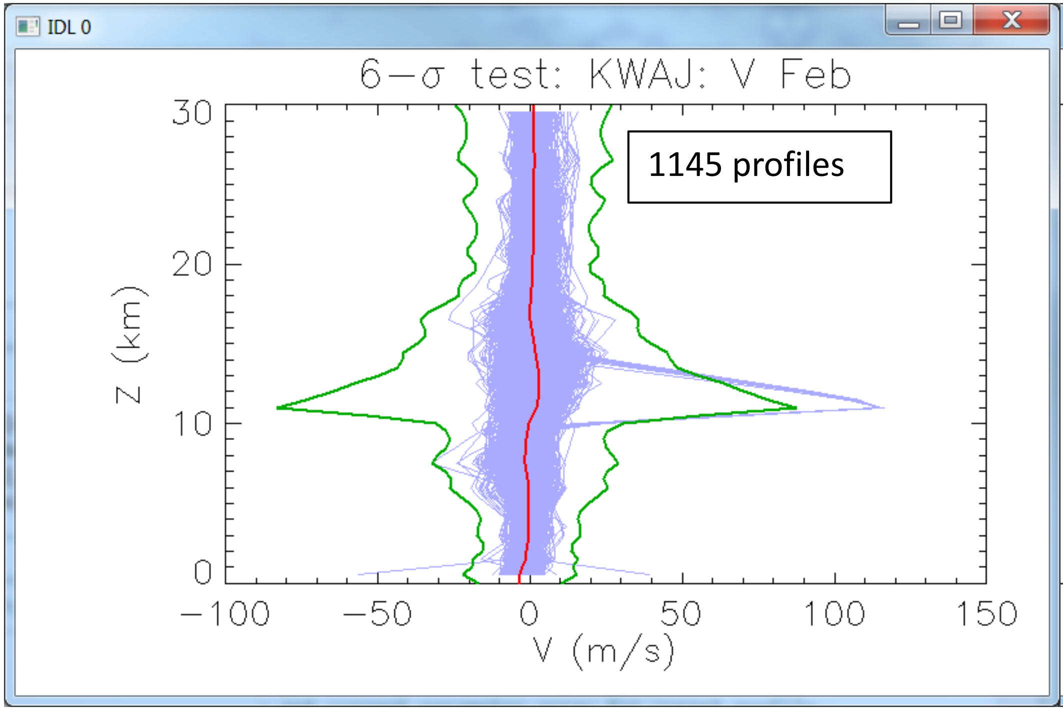
Step 8: Diagnostic Testing

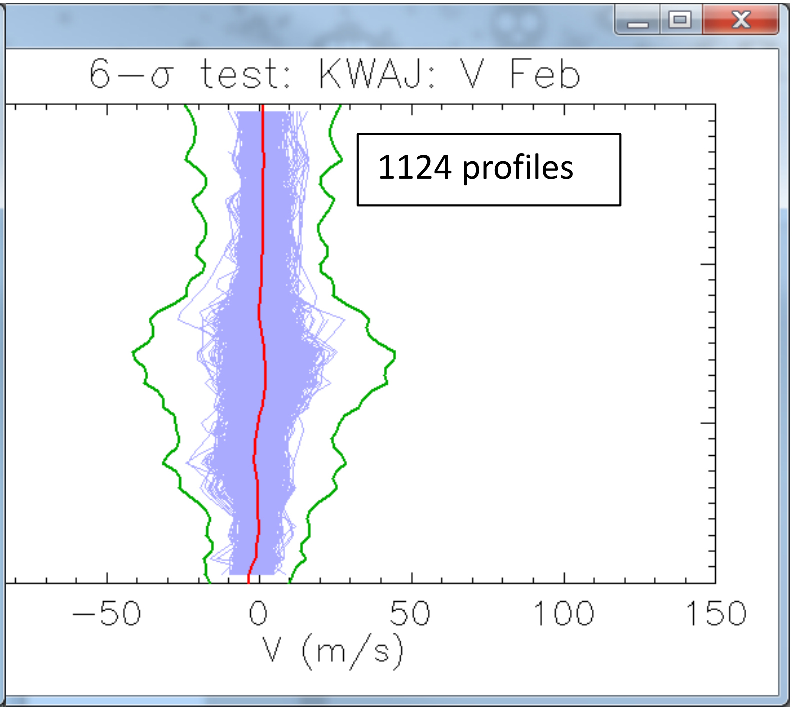
Tests performed independently for U, V, WS, T, Td, and P.

- Computed RRA mean values and standard deviations are used to produce $\mu \pm 6\sigma$ envelopes for each month.
- All constituent profiles are compared to the envelopes.
- If all profiles are within the envelopes, then diagnostic testing is complete and process continues on to validation testing.
- Any profile with any value outside the respective envelopes are removed from the set of interpolated profiles. Once this is complete, then step 7 is repeated with the new set of input profiles.
- This cycle is iterated until there are no envelope exceedances.

JACOBS ESSSA Group

Diagnostic Testing Results (Example)





Step 9: Validation Testing

A total of ten validation tests are performed

- Five skewness tests: P, T, Td, D, WS.
- Three Buell relationship tests.
- Gas law reconstruction test.
- Wind component reconstruction test.

JACOBS ESSSA Group

Validation Testing: Skewness

Monthly skewness values at each altitude are compared to established limits. Any noted exceedances are flagged as failures.

Parameter	Valid Skewness Condition	
WS	$SKEW \leq 4.0$	for $\mu_{WS} < 15$ m/s
	$SKEW \leq 2.5$	for $\mu_{WS} \geq 15$ m/s
P	$-2.5 \leq SKEW \leq 2.5$	
T	$-2.5 \leq SKEW \leq 2.5$	
D	$-3.5 \leq SKEW \leq 3.5$	
TD	$-2.5 \leq SKEW \leq 2.5$	

Validation Testing: Buell Relationships

Equalities relating thermodynamic statistical parameters. Any month/altitude combinations where |LHS-RHS| > 0.1 are flagged as failures.

#1

$$\frac{\sigma_P}{\mu_P} = \sigma_D \cdot \frac{r_{P,D}}{\mu_D} + \sigma_T \cdot \frac{r_{P,T}}{\mu_T}$$

#2

$$\sigma_P \cdot \frac{r_{P,D}}{\mu_P} = \frac{\sigma_D}{\mu_D} + \sigma_T \cdot \frac{r_{T,D}}{\mu_T}$$

#3

$$\sigma_P \cdot \frac{r_{P,T}}{\mu_P} = \frac{\sigma_T}{\mu_T} + \sigma_D \cdot \frac{r_{T,D}}{\mu_D}$$

Buell, C.E., Some relations among atmospheric statistics, *J. Met.*, **11**, 1954

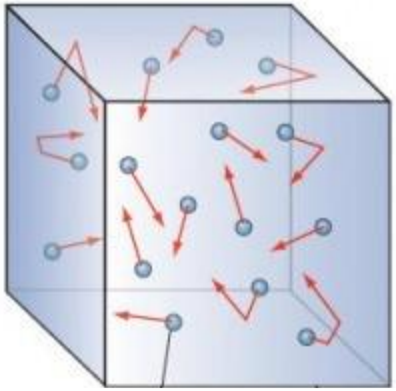
Thermodynamic correlation terms are not part of RRA output but are computed concurrently for this test

Validation Testing: Gas Law Reconstruction

Specific gas constant, R, is derived from output RRA mean values and compared to the accepted value. Any differences greater than 0.5 J kg^{-1} K^{-1} are flagged as failures. Note that this test is only applied above 10 km, where the air is assumed dry.

$$R_{RRA} = \frac{P}{D \times T}$$

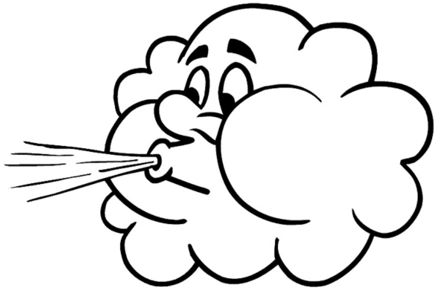
$$R_{accepted} = 287.058 \text{ J kg}^{-1} \text{ K}^{-1}$$

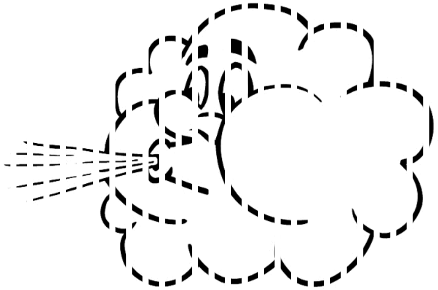


Validation Testing: Wind Reconstruction

Assuming a bivariate normal distribution of the U and V wind components, the component statistics (mean and standard deviations) can be related to the wind speed statistics. A monthly mean wind speed estimate is computed from this relationship and compared to the RRA mean wind speed. Any differences greater than 3 m/s are flagged as failures.

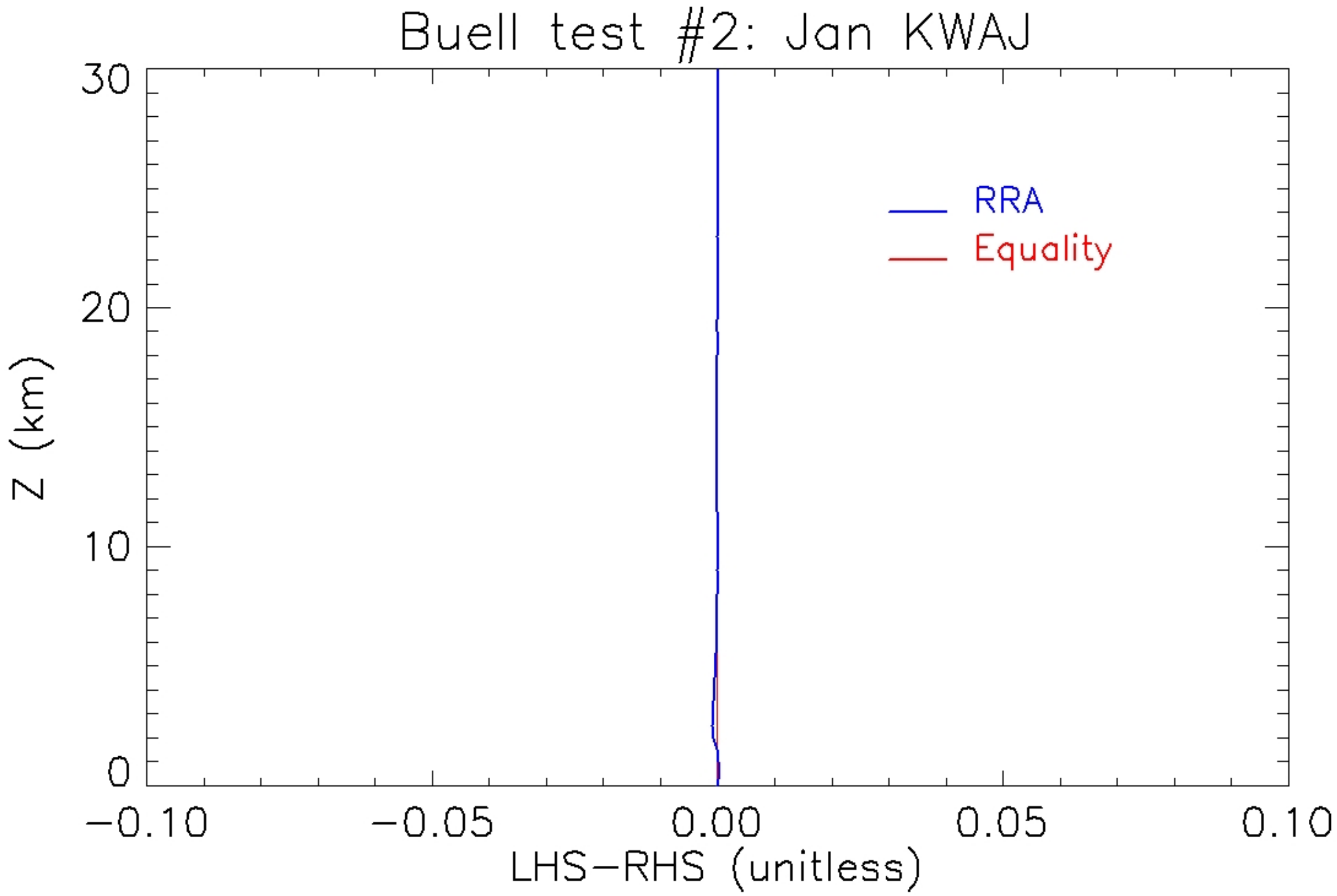
$$\mu_{WS,estimate} = \sqrt{\mu_U{}^2 + \mu_V{}^2 + \sigma_U{}^2 + \sigma_V{}^2 - \sigma_{WS}{}^2}$$





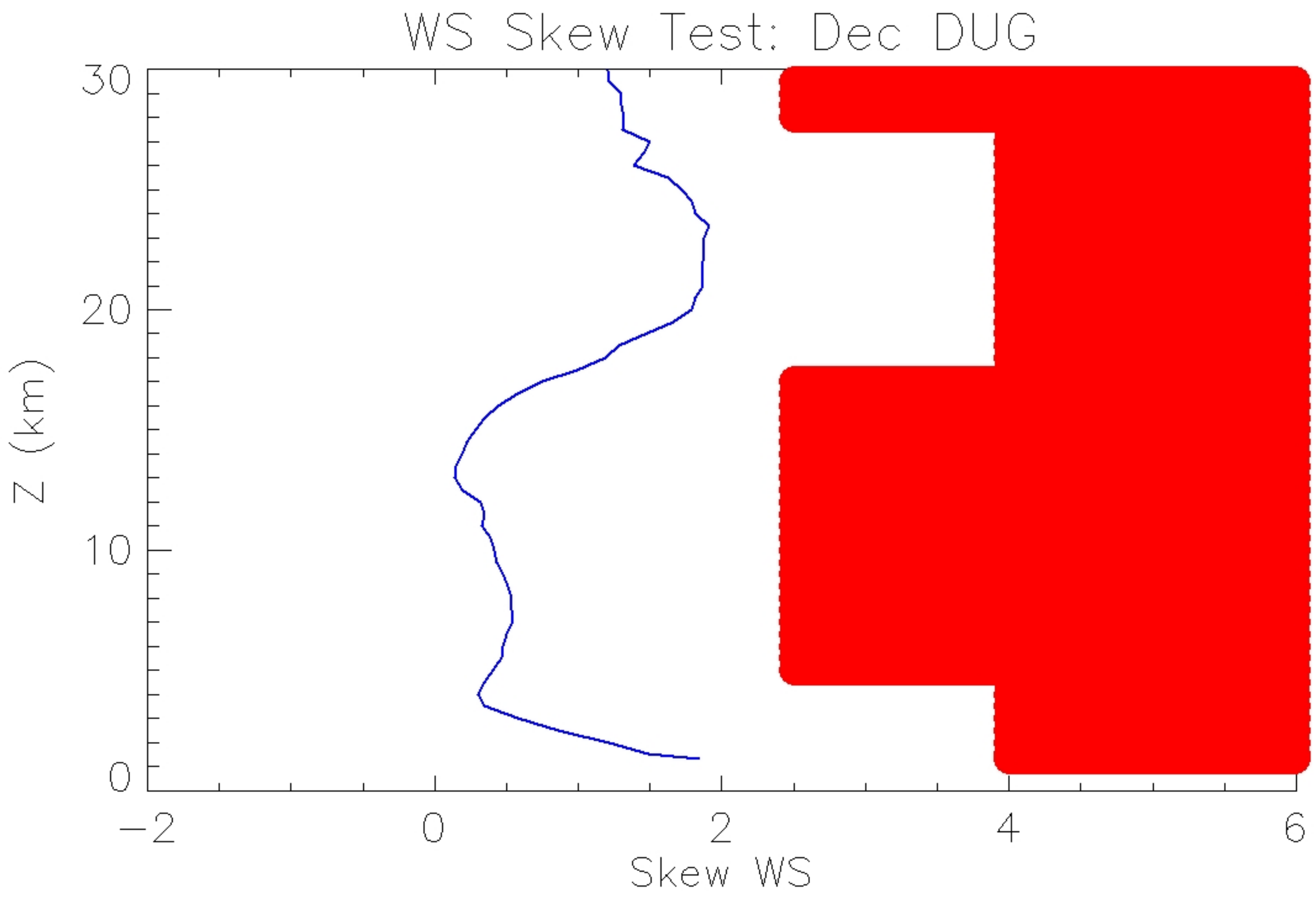
Validation Testing Results (examples)

Buell Relationships



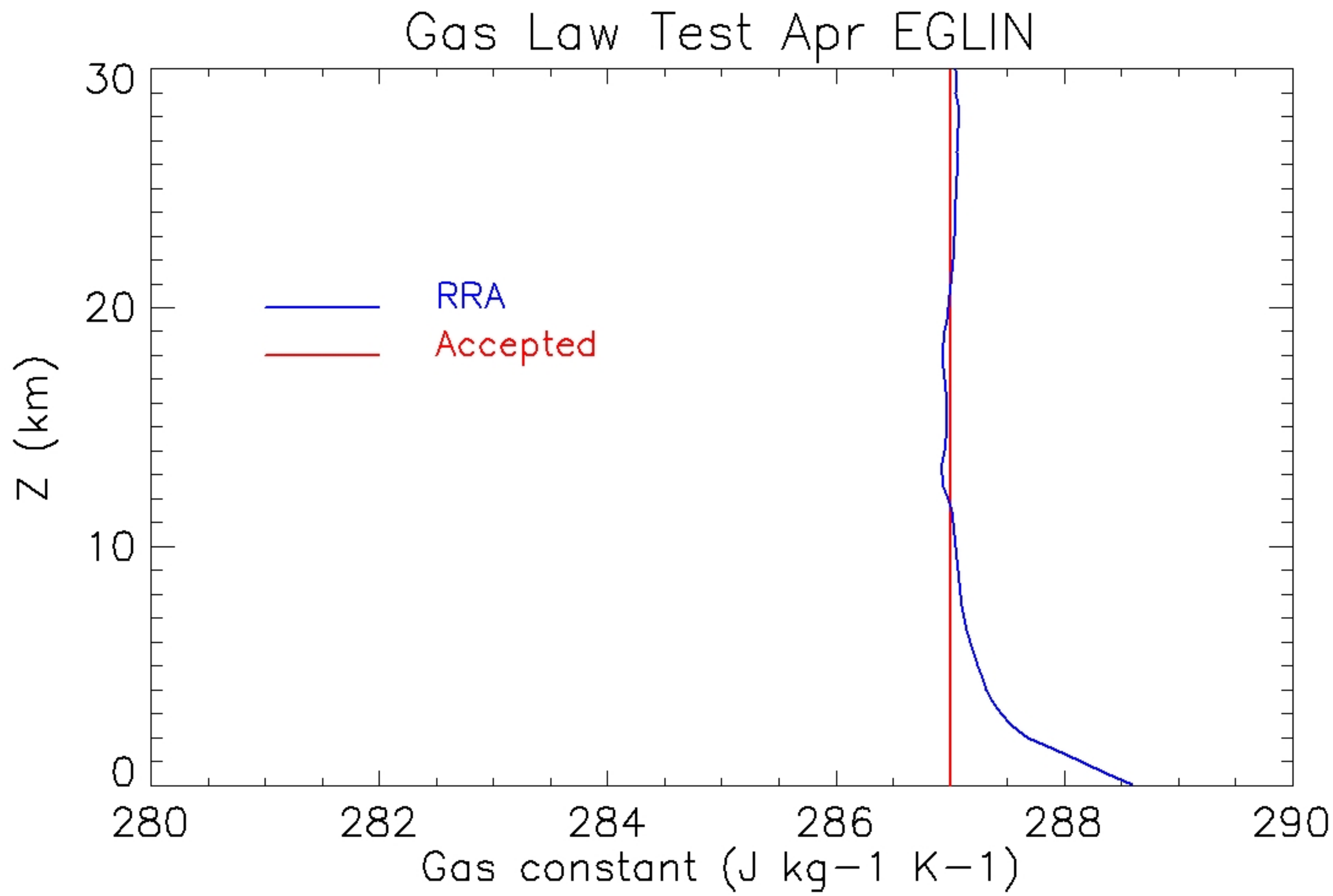
Validation Testing Results (examples)

Wind Speed Skewness



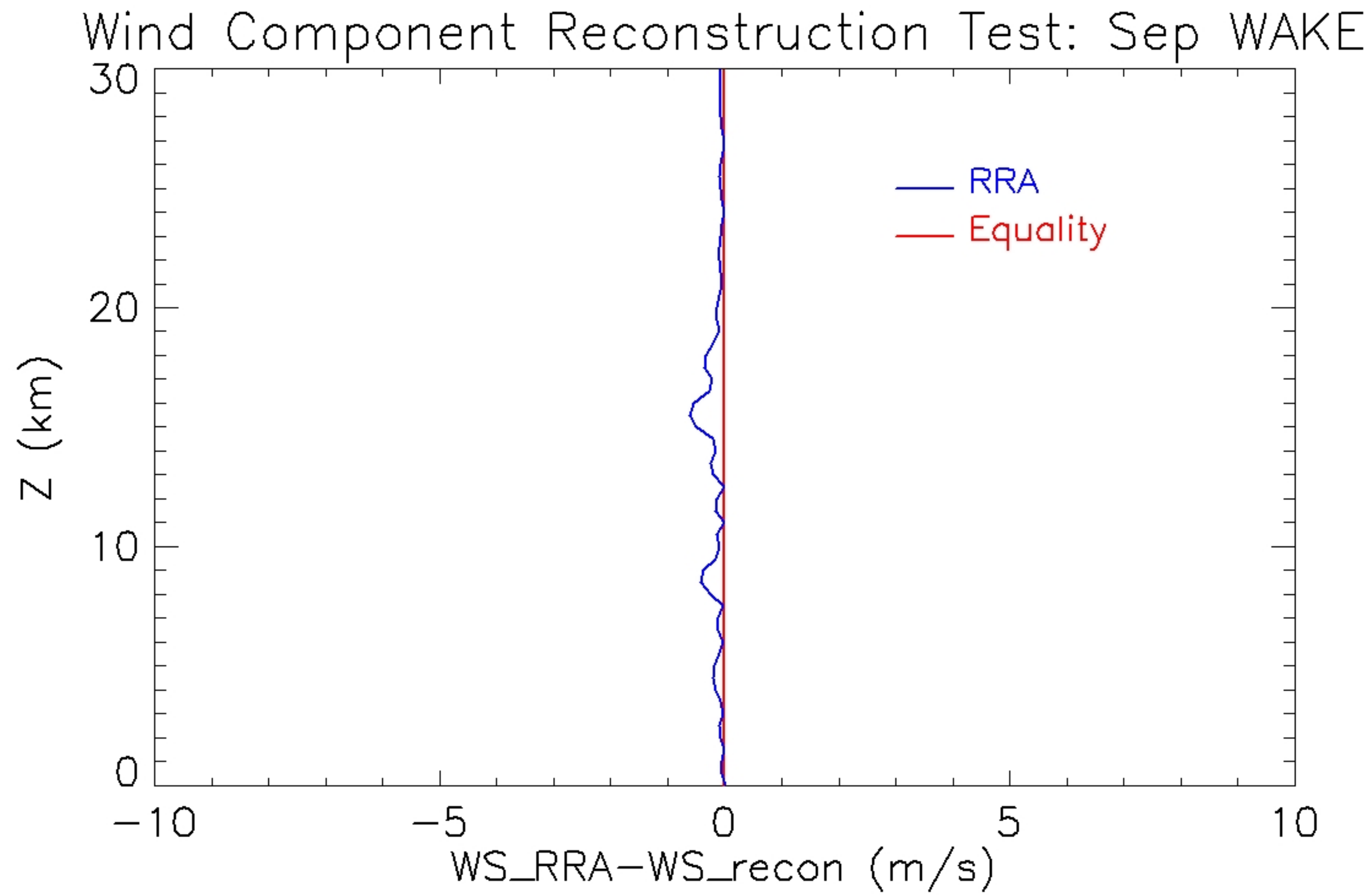
Validation Testing Results (examples)

Gas Law Reconstruction



Validation Testing Results (examples)

Wind Speed Reconstruction



Validation Testing Notes

- All tests are performed analytically. Graphs are only used for visualization.
- A validation test "failure" does not identify the particular bad profile(s) causing the failure. If a failure is noted, then various idiomatic secondary analyses are performed to identify the profiles causing the failure condition. This process is highly interactive and relies heavily on SME experience and judgment.
- After a dataset passes all validation tests, then an independent validation is performed by other EV44 personnel using separately implemented methodology.

Step 8: Post-Processing/Documentation

- Generate plots of all RRA statistical parameters.
- Save RRA data to Excel spreadsheet format.
- Save timestamp listing and inventory files for all profiles used for final RRA production.
- Create Earth GRAM-formatted text files.
- Produce RRA development reports for each site.
- Send Excel files and development reports to the RCC-MG Meteorological Support Committee chair, for posting on the EAFB weather office web site.

JACOBS
ESSSA Group

Summary

- New RRA datasets have been created for 15 sites. These are available on the EAFB weather office web site.
- The New RRAs are also available, in Earth-GRAM format, by requesting Earth-GRAM 2010 V.4 from EV44. POC is

  Patrick White

  256-544-5776

  Patrick.W.White@NASA.gov
- Now that EV44 has developed the capability, we would like to support additional future developments. Providing this support operationally may require some finagling. Due to the nature of the process and the necessity of SME interaction, EV44 would prefer not to give out our software to avoid potential misapplication.

Questions

JACOBS ESSSA Group

Periods of Record Used

SITE	Start POR	End POR	# Profiles	Data Source
Cape Canaveral	11/26/1988	12/31/2011	16813	Station
Edwards	1/2/1990	4/4/2012	9291	Station
Vandenberg	12/2/1992	1/7/2013	9733	Station + IGRA
White Sands	1/2/1992	8/26/2012	9055	IGRA
Wallops	1/1/1990	1/7/2013	15108	Station + IGRA
China Lake	1/8/1980	12/18/1997	3506	IGRA + ESRL
Point Mugu	1/23/1971	8/27/2013	8386	IGRA + ESRL
Dugway	1/1/1990	11/17/2013	15817	IGRA
Yuma	10/19/1971	12/24/2013	8650	IGRA + ESRL
Eglin	1/28/1980	11/13/2013	11909	IGRA
Kwajalein	1/1/1990	11/17/2013	14772	IGRA
Kodiak	1/1/1990	11/17/2013	16465	IGRA
Wake Island	1/1/1980	5/13/1997	11839	IGRA
Barking Sands	1/1/1980	1/27/2015	17037	IGRA
Thule	1/1/1980	10/10/2006	13418	IGRA