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Status of the KSC Tropospheric Doppler Radar Wind Profiler Acceptance Test for SLS Certification

BJ Barbré

Jacobs ESSSA Group

MSFC Natural Environments

7 September 2017

Presentation to the Natural Environments Day of Launch Working Group

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Outline

- Background
- Data and Methodology
- Results
- Summary

Background

- Tropospheric Doppler Radar Wind Profiler (TDRWP) certification analyses consist of examining TDRWP output and comparisons to balloon measurements.
  - Analyses assume that the balloon is valid while accounting for temporal sampling differences between the balloon and TDRWP.
  - Include examination of TDRWP data quality, effective vertical resolution (EVR), and "reliability".
    - "Reliability" defined as the percent of possible timestamps that a usable profile is available.
    - "Usable" defined as a profile containing data that pass the quality control (QC) process described herein.
  - Full certification [specific to NASA Space Launch System (SLS)] to certify use of TDRWP in vehicle performance assessments for GO/NOGO decision to launch. Data have been collected over one year.
  - Interim analyses performed by MSFC Natural Environments (NE):
    - Quick-Look (performed for the ER/KSC) determined that the TDRWP produces data that is of sufficient quality to assess for the Operational Acceptance Test (OAT). Completed in July, 2016.
    - OAT, performed for the Eastern Range (ER) / Kennedy Space Center (KSC)
      - Concluded that the new system is as good as the 50-MHz DRWP*, and could be used as a situational awareness tool.
      - Noted a decrease in EVR from a previous OAT due to changes of transmission frequency, pulse shape, pulse width, and processing software, which necessitated a redo of the TDRWP certification process.
- These charts summarize the analysis method and provide a status of analyses supporting the TDRWP full certification for SLS.
- *Individual vehicle programs must decide if and how to use the TDRWP.*

** The term "50-MHz DRWP" refers to the system that the TDRWP is replacing (i.e., the system that was decommissioned in March 2014).*

Certification Requirements

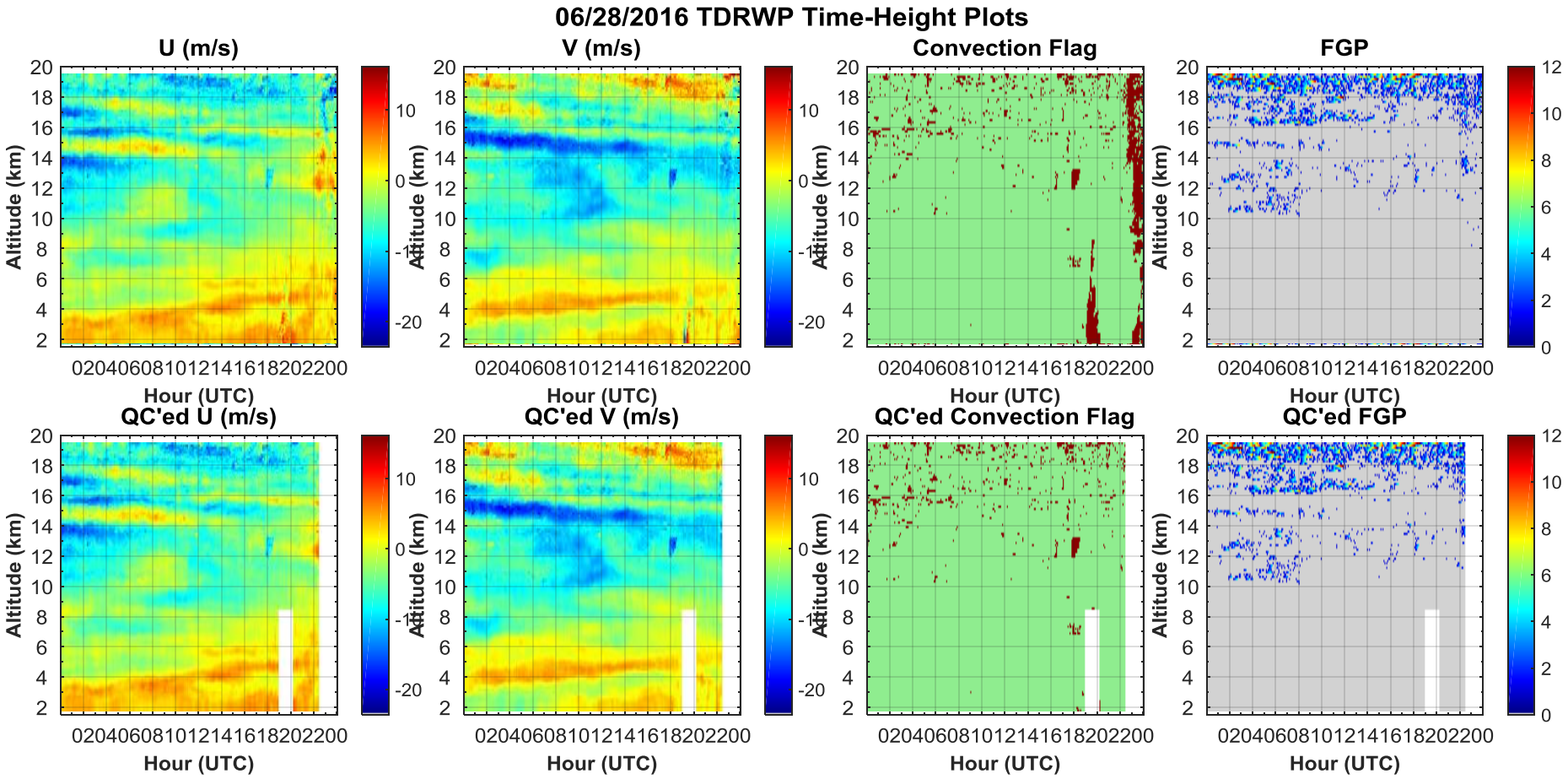
Requirement	Criteria	Rationale
Time Interval	5 min	Supports DOL timeline.
Vertical Data Interval	150 m	Consistent with database used for SLS design.
Altitude	2,700 - 15,250 m	Consistent with database used in SLS design.
Wind Accuracy	1.5 m/s root-mean-square component difference	Accuracy of heritage balloon and DRWP systems.
Reliability	No criterion. Will report the percent of usable profiles.	Consistent with the method Shuttle used to certify AMPS.
Effective Vertical Resolution	700 m	Based on maximum wavelength of gust analyses during SLS design.
Data Collection Period	One year	Analyzing available data over one year of continuous operation produces statistically significant results over all seasons.

- Time interval passes criteria under nominal operations.
- Vertical data interval passes criteria.
- Using data quality to assess altitude criteria.
- Max wavelength of gust analyses is based on accounting for a 30-minute assessment.
  - Aerospace Corporation equation: WL = [460 * sqrt(T)] yields 768 m.
  - Set criterion to 700 m to add conservatism.

Data and Methodology

- TDRWP Data
  - Five-minute profiles for each day from 1,795-19,430 m, every 150 m.
  - QC for balloon comparisons: Removed profiles during periods of deep convection that affected the wind field.
  - Each day contains at least 100 profile pairs (prerequisite for spectral analysis).
- Balloon Data
  - Automated Meteorological Profiling System (AMPS) Low Resolution (LR) and High Resolution (HR) Flight Element (FE).
  - One-second data provided by the Cape Weather Station.
  - Performed altitude limit (15.25 km, or 50 kft) and temporal separation (5 mins) QC.
- Analysis period
  - Balloon and TDRWP data collected from June 22, 2016 to June 22, 2017. Balloon data through 6 June 2017 have been processed.
  - A total of 881 concurrent balloon and TDRWP profiles exist for analysis.
- Analysis methodology
  - Visually examine TDRWP time-height (T-Z) sections.
  - Investigate QC flags.
  - Compute root-mean-square (RMS) wind deltas from TDRWP and balloon profiles matched in the temporal and vertical domain.
  - TDRWP spectral analysis to quantify EVR.
  - Beginning work for reliability analysis.

Example TDRWP T-Z Section



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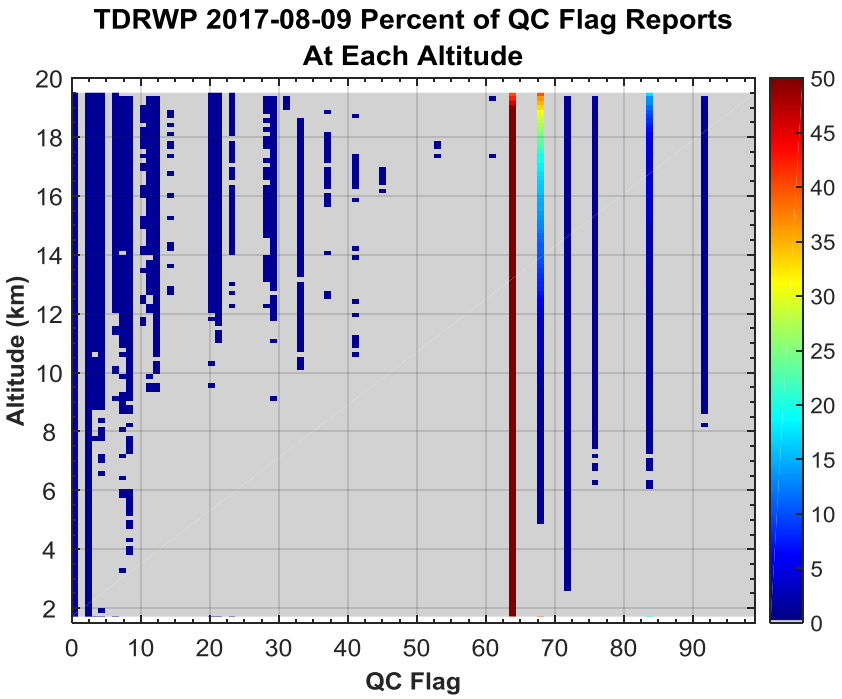
QC Flag Investigation



- Analysis takes advantage of QC flag reports unique to the TDRWP.
- SNR check failure is responsible for many QC flag instances.
- Some QC flags (including 0, 1, 3, and 64) do not indicate suspect or erroneous data.

QC Flag	Description
0	Auto QC. Communication to MMQC normal.
1	Manual QC Active either at the MMQC or MSC
3	Manual QC Active, Automated Release
4	Auto QC, SNR
5	Manual QC Active, SNR
7	Manual QC Active, Auto Release, SNR
8	Auto QC, Shear
9	Manual QC Active, Shear
11	Manual QC Active, Auto Release, Shear
12	Auto QC, SNR, Shear
13	Manual QC Active, SNR, Shear
15	Manual QC Active, Auto Release, SNR, Shear
20	Auto QC, SNR, Shear
21	Manual QC Active, SNR, Shear
23	Manual QC Active, Auto Release, SNR, FGP
28	Auto QC, FGP, Shear, SNR
29	Manual QC Active, FGP, Shear, SNR
31	Manual QC Active, Auto Release, FGP, Shear, SNR
33	Manual QC Active, Bad Data
61	Manual QC Active, Bad Data, FGP, Shear, SNR
64	Auto QC.
68	Auto QC, SNR
72	Auto QC, Shear
76	Auto QC, SNR, Shear
84	Auto QC, SNR, FGP
92	Auto QC, FGP, Shear, SNR

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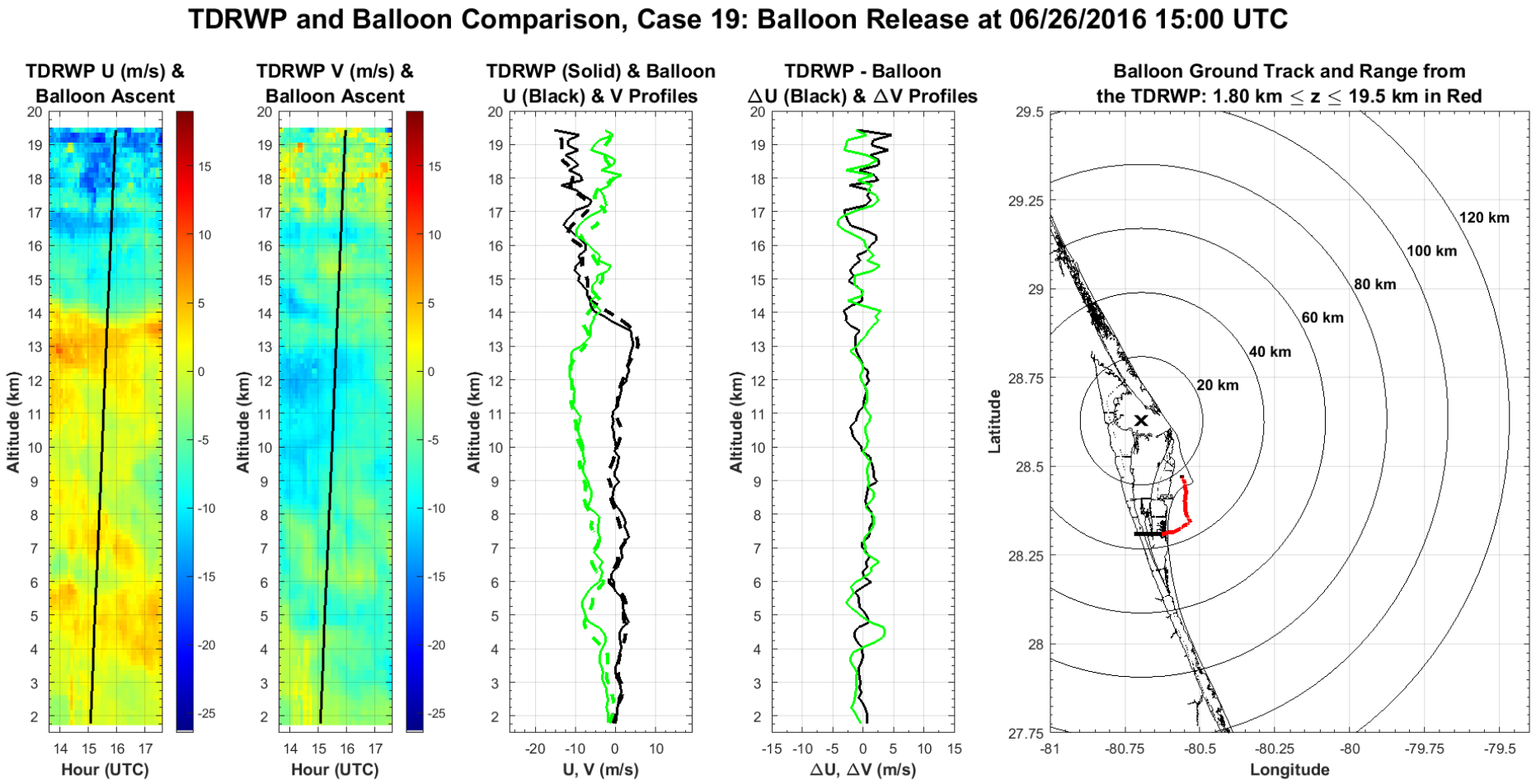
Example TDRWP / Balloon Comparison: Noisy Data



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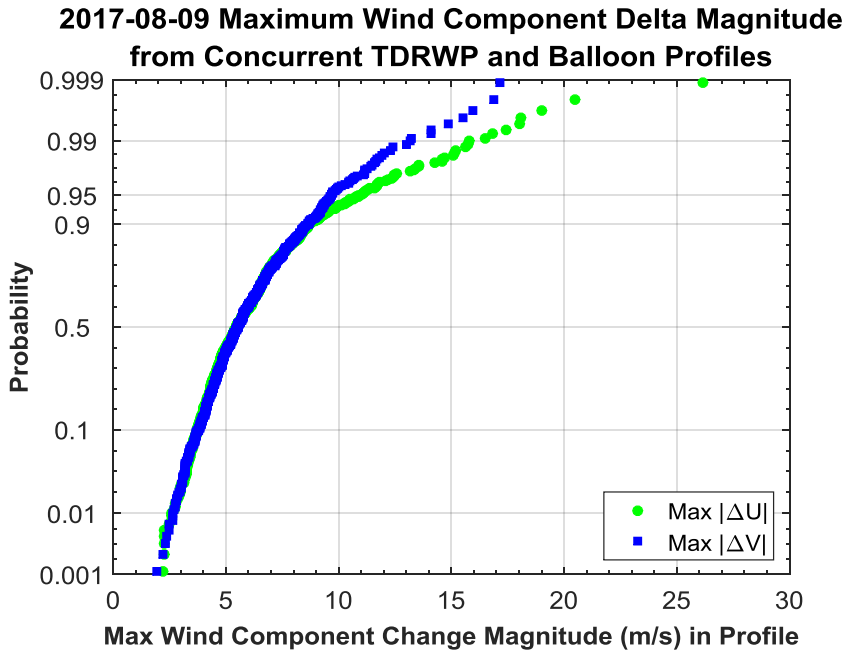
Examination of Wind Component Deltas

- Some large deltas noted when examining individual profile comparisons.
- Plotted the distribution of the maximum wind component delta magnitude (N = 881).
- Applying additional scrutiny to profiles which contained maximum delta magnitudes of at least 10 m/s.
- In process of removing profile comparisons affected by meteorological differences between TDRWP and balloon sampling environments.



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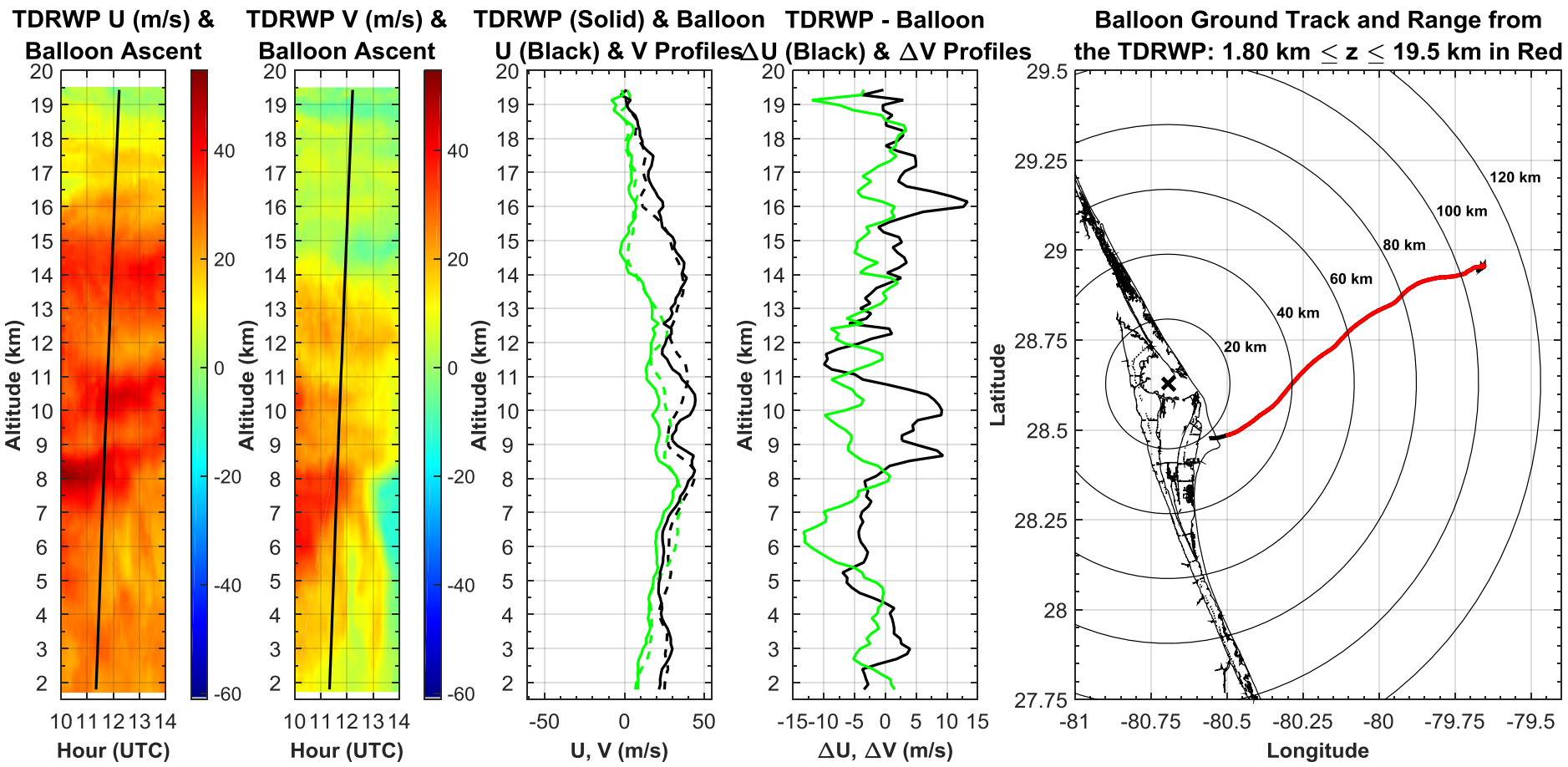
Example TDRWP / Balloon Comparison: Meteorological Influence



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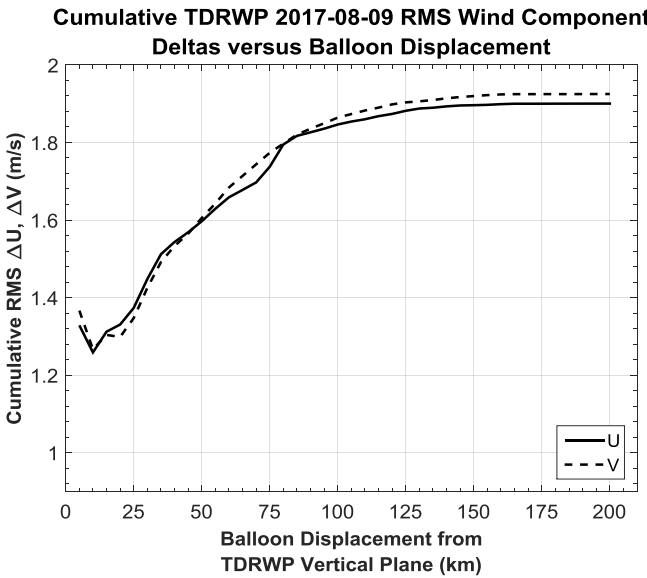
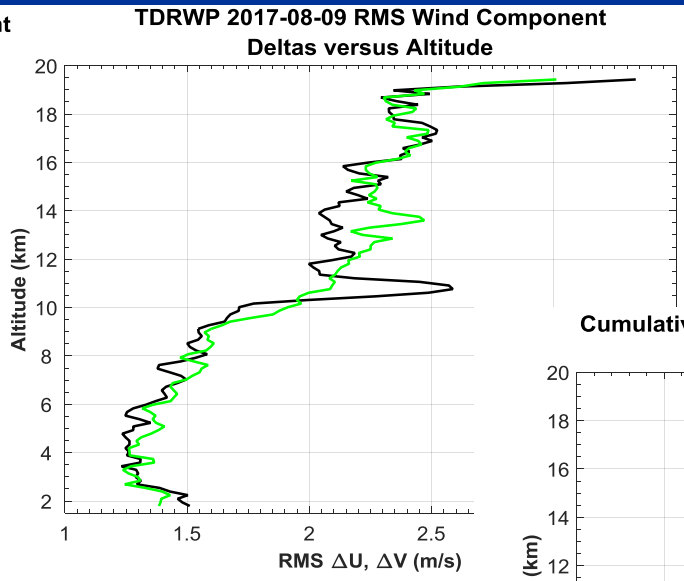
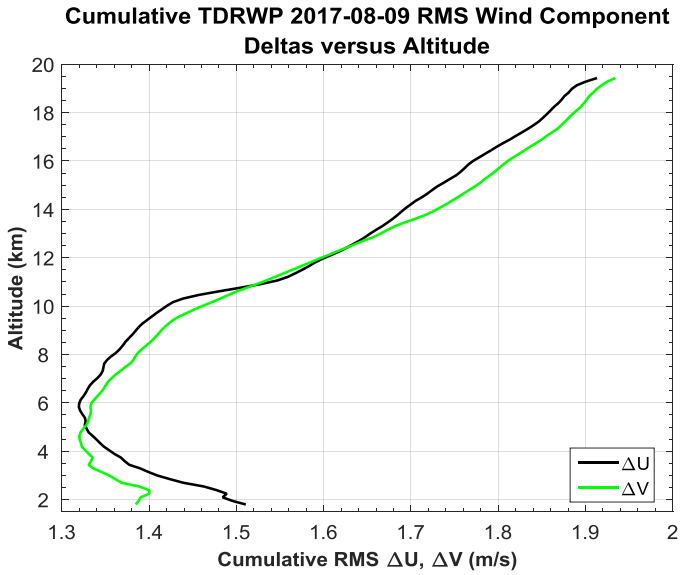
Preliminary Wind Component Deltas







- RMS deltas are ~1.9 m/s for U and V without removing any comparisons due to meteorological influence.
  - Expect improvement after removing these cases.
  - Consistent with expected differences between measurement systems.
  - OAT RMS deltas were ~2.1 m/s using data collected during winter.
- Variations in wind deltas noted conditional to balloon displacement and altitude.
  - RMS deltas cross 1.5 m/s around 30 km displacement and 10 km altitude.
  - Specifics could change after removing meteorological-influenced comparisons.

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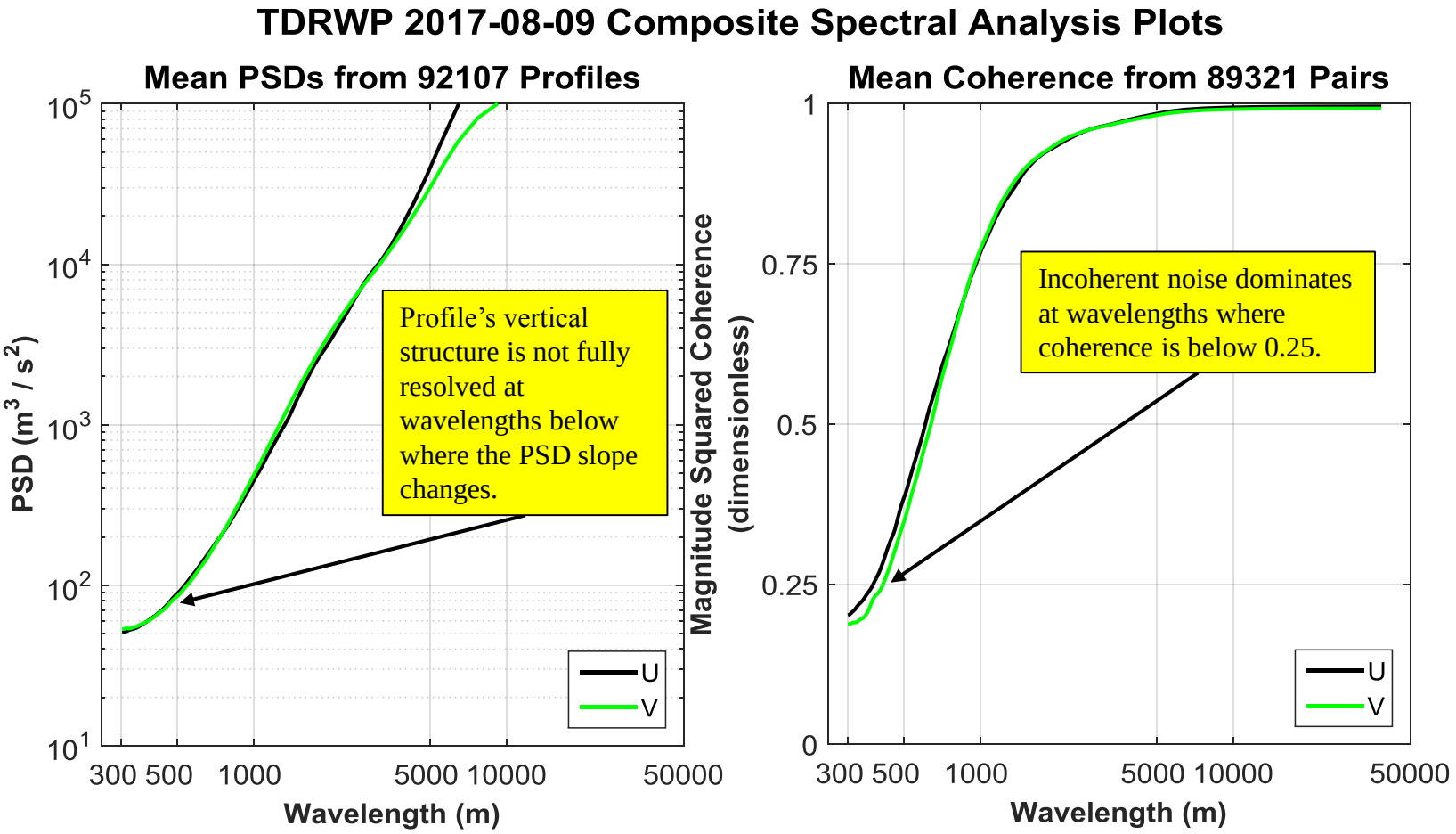
EVR



- TDRWP EVR appears to be ~400 m.

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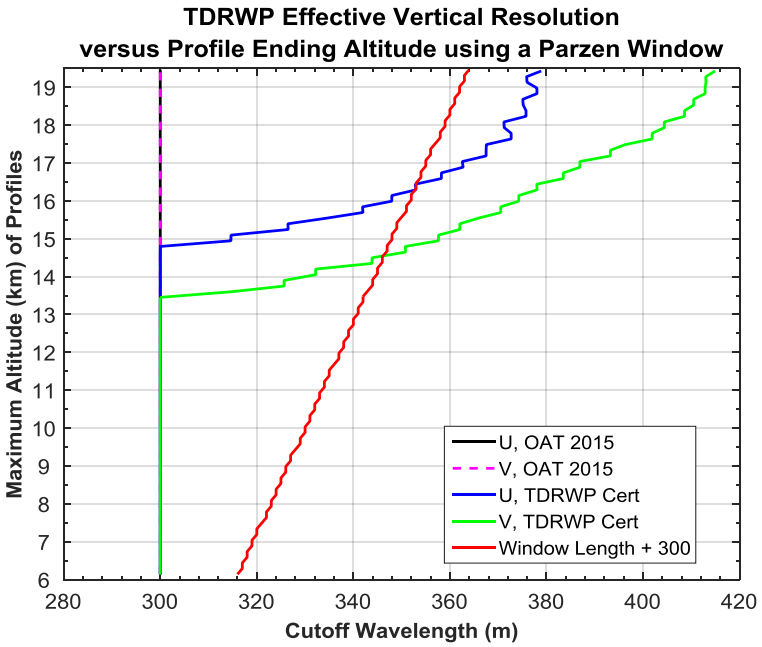
EVR Sensitivity to Altitude

- Performed coherence analysis after truncating TDRWP profiles at specified altitudes.
  - Used same profiles for each case.
  - Adjusted window size to be proportional to input signal length.
  - Plotted cutoff wavelength versus ending altitude.
  - Similar results from Parzen and Hanning windows.
- TDRWP is Nyquist-limited when assessing profiles to ~13-15 km.
  - Highlights the altitudes where noise starts to influence EVR.
  - Data from the initial OAT (2015: before amateur radio issue) are Nyquist-limited for the entire profile.
- Results indicate that increasing signal power might improve EVR.



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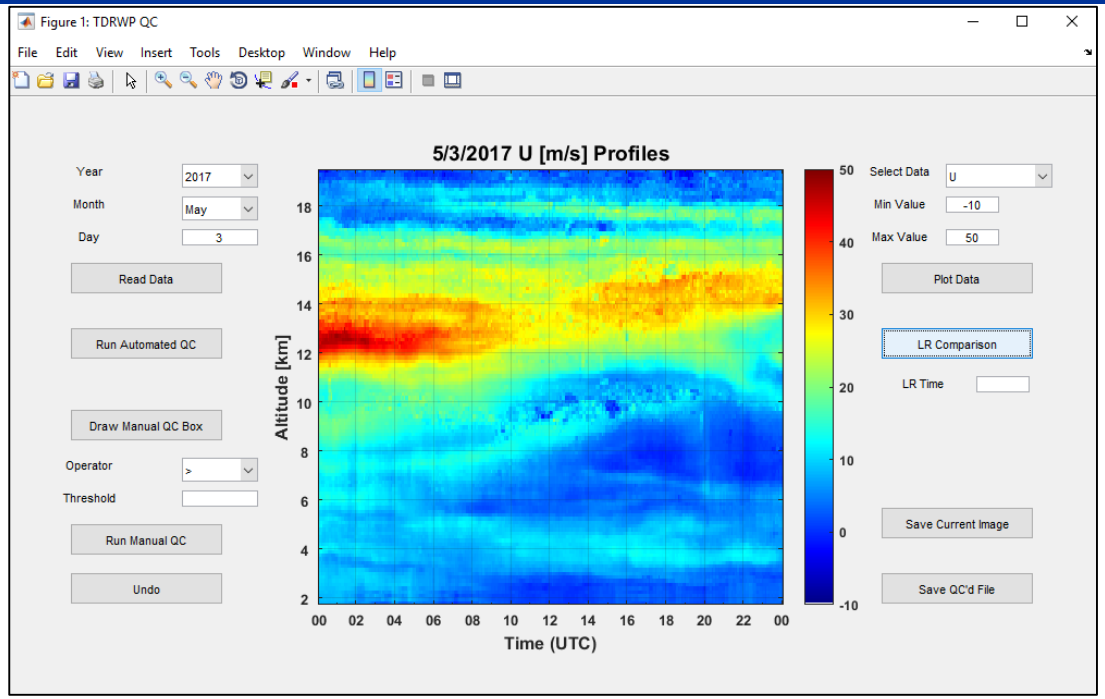
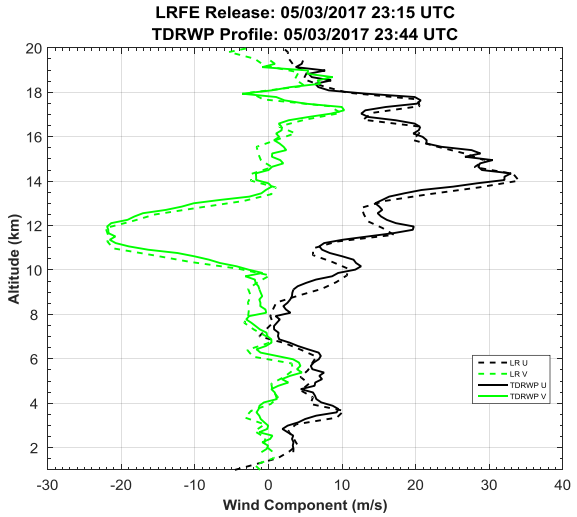
Reliability





- Built QC interface for TDRWP data, and implementing QC process on each day.
- Developed QC criteria
  - Largely derived from process used to build the MSFC NE QC'ed 50-MHz DRWP database.
  - Developed new criteria for "noisy" data.
  - Developing new criteria for FGP exceedance, which requires spectral data for selected periods.
- Intend to use QC'ed database to determine the percent of usable profiles that reach specified altitudes.

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Summary

- This presentation provides a status of activities performed for the TDRWP full certification for SLS.
  - TDRWP wind profiles compare well with concurrent balloon measurements.
    - Wind component deltas are generally smaller if balloon is closer to TDRWP.
    - Analysis shows expected results when considering data from previous testing.
  - TDRWP EVR appears to be ~400 m.
  - Caveat exists in that the TDRWP contains instances of weak signal at high altitudes.
    - Results in noisy data.
    - Sensitivity study links EVR with maximum altitude.
  - Results presented are preliminary and subject to change once the analysis is completed.
- Forward work
  - Add balloon data from 7-22 Jun 2017 to profile comparisons.
  - Remove comparisons where the balloon and the TDRWP sample different wind environments.
  - Complete data QC, FGP analysis, and subsequent reliability analysis.
  - Document findings in a report.

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Backup

- Data and methodology details
- Analysis of time interval between adjacent profiles
- RMS vs balloon displacement and altitude
- Example QC flag T-Z section

Backup: Data Details

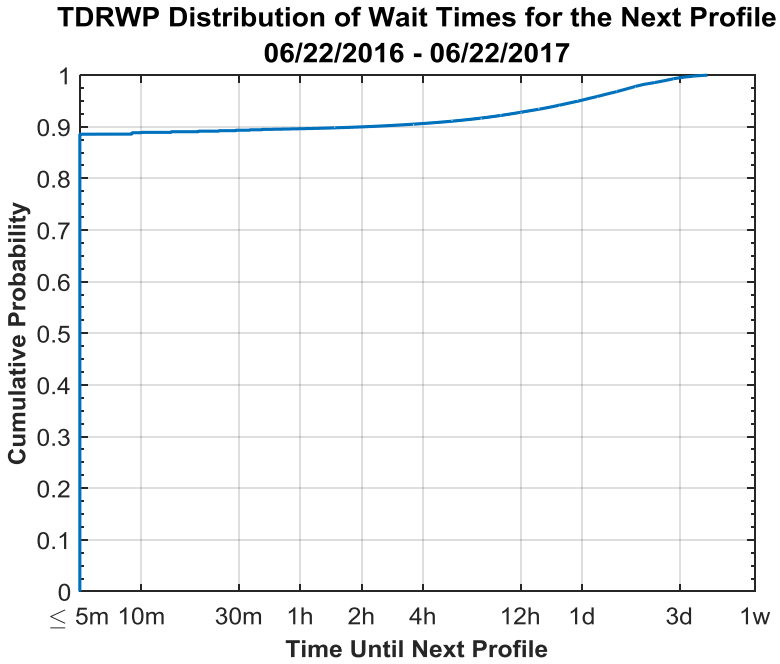
- TDRWP
  - Five-minute profiles for each day from 1,795-19,430 m, every 150 m.
  - Filled temporal data gaps for plotting.
  - Removed entire profiles during periods of deep convection that affected wind field (“QC”).
  - Each day contains at least 100 profile pairs.
- Balloon
  - Automated Meteorological Profiling System (AMPS) Low Resolution (LR) and High Resolution (HR) Flight Element (FE).
  - One-second data provided by the Cape Weather Station.
  - Variables processed for analysis consist of date, latitude, longitude, altitude, and smoothed wind components at each altitude up to 22,860 m (75,000 ft).
  - Profile must terminate at or above 15,240 m (50,000 ft) and not contain a 31 m (100 ft) vector shear exceeding 0.15 s^{-1}.
  - Separated temporally adjacent profiles by at least five minutes to avoid processing duplicate balloon profiles.

Backup: Methodology Details

- Plotted TDRWP time-height (t-z) sections of wind components, convection, and maximum first-guess-propagation (FGP) from all four beams.
- TDRWP / Balloon comparisons
  - Averaged all one-second balloon data within 75 m of each TDRWP altitude. At least 15 one-second reports must exist to report an average.
  - Temporally matched balloon and TDRWP data throughout balloon ascent.
    - Subtracted 7.5 minutes from TDRWP timestamp to account for temporal averaging.
    - Found closest TDRWP record to the balloon timestamp at each altitude.
    - TDRWP record must exist within five minutes of balloon timestamp.
  - Retained profile for comparison if at least 75% of the 119 TDRWP altitudes (i.e., range gates) contain reports from both sources.
  - Total of 30 balloon (all LRFE) profiles with concurrent TDRWP profiles existed that passed QC during the analysis period.
  - Plotted TDRWP wind component t-z sections with balloon ascent, TDRWP / balloon overlay and differences, and balloon ground track.

Backup: Analysis of Time Interval

- Created a vector of 5-min timestamps over the POR.
- For each 5-min timestamp, found the time until the next profile from the database (i.e., “wait time”).
- Plotted the cumulative distribution of wait times.
- Results show the probability of waiting for a given time before the next profile.



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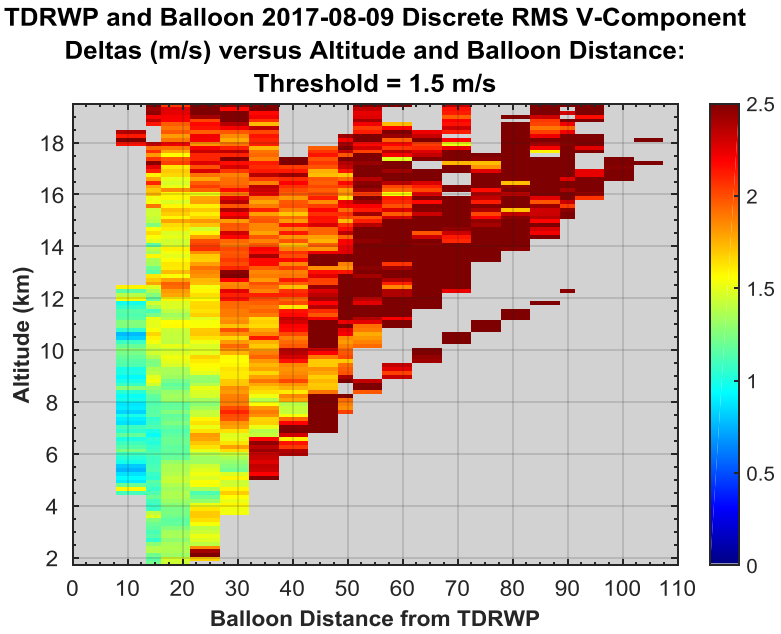
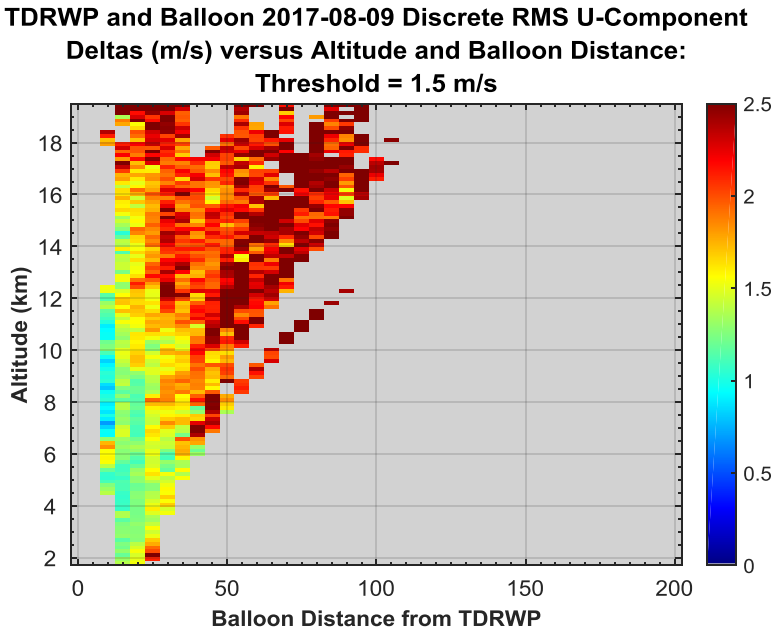
Backup: RMS vs Balloon Displacement and Altitude





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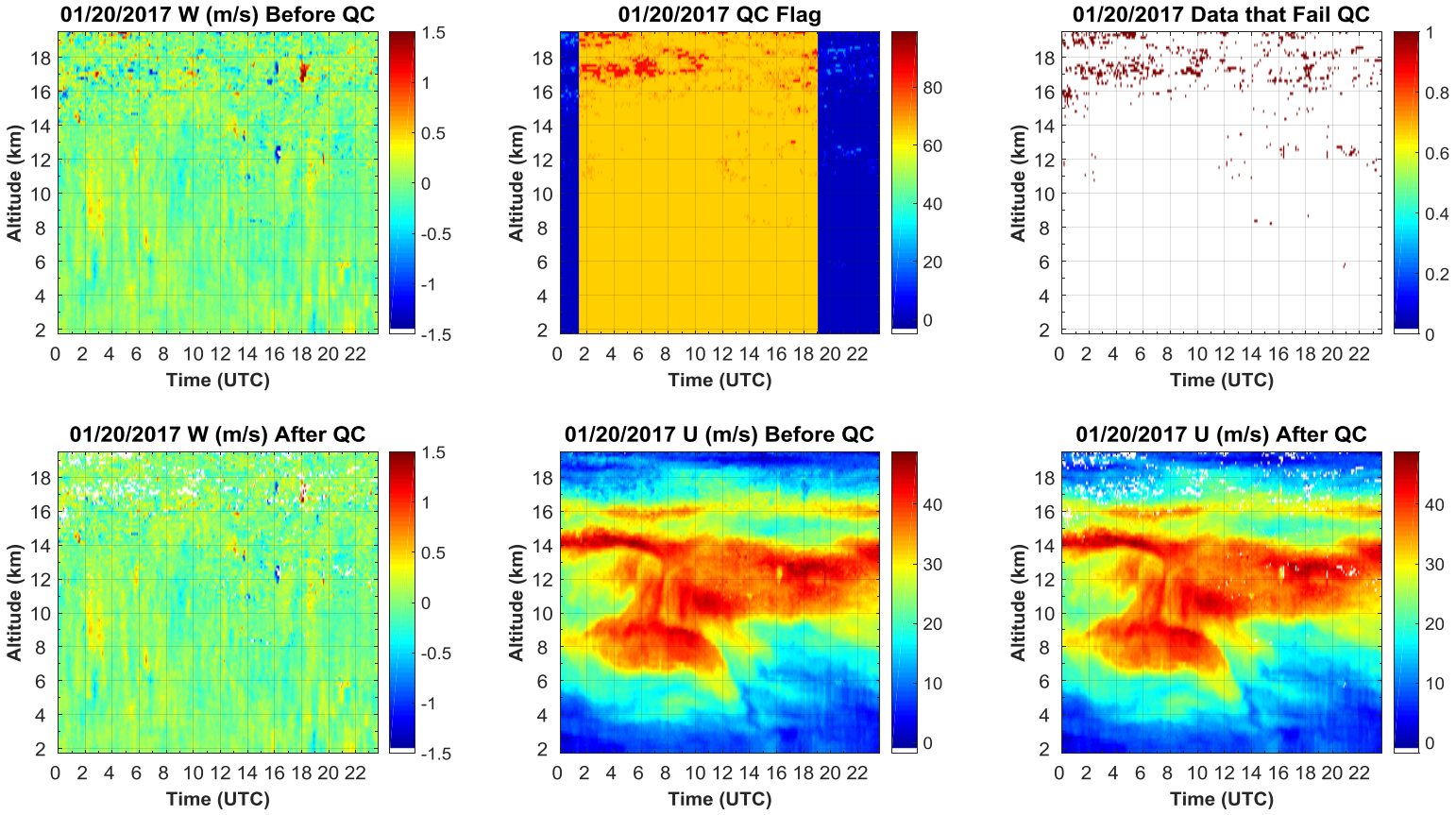
Example TDRWP T-Z Section with QC Flag



- Noted extensive areas of noisy data at high altitudes, as primarily indicated by w.
- Examined criteria for excessively noisy data QC: |w| > 0.5 m/s and QC flag for SNR, shear, or FGP tripped.

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