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Appendix to TORERO Project Manager's Report: Reprocessing

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The NCAR/EOL Research Aviation Facility has recently completed a review and upgrade of its existing algorithms for data processing to incorporate recent improvements that have become available for specific instruments. The complete documentation of RAF's standard algorithms can be found in the RAF Technical Note on Processing Algorithms (Cooper, 2016) and is available at https://www.eol.ucar.edu/content/raf-processing-algorithms. These are living documents and changes may be made at any time in the future.

Recently RAF reprocessed all GV projects between 2008 and 2014 to incorporate many updates to the processing code. This reprocessing provided consistency across all projects with earlier projects having more changes than later ones. Many of the changes do not have a large effect on the data, but the processing updates are presented here for transparency and to provide background information on data quality issues.

RAF has performed quality control on the reprocessed flight data and is releasing it with this addendum to the project manager's report. Section I in the present document provides a description of the specific upgrades to the processing code made for TORERO. In most cases the changed variables supersede those described in the original project manager's report. The modifications to the data and impacts on individual flights will be described in Section II.

Section I - Summary of Changes to the Processing Code

Temperature
Soon after the GV entered service, comparisons were made between the various on board temperature measurements and dropsondes, utilizing flight maneuvers that followed the descent of dropsondes so that the measurements could be made in the same airmass at nearly the same time and near the same location as the dropsonde. These studies revealed a problem with the standard calibration of research temperature probes and indicated that the temperature data that matched the sonde data best was the avionics temperature (which is taken from the onboard avionics system and used for aircraft flight data and avionics control systems). Consequently, until recently the reference temperature (ATX) for projects was taken from the avionics temperature (AT_A). Now that the problems with the calibration system have been resolved, the data are reprocessed to use the measurements from the research temperature instruments as the reference temperature, which provides better accuracy and time response than is available from the avionics temperature.

A large-scale effort to understand the calibration issue found that there were two primary problems with the bath calibrations: (i) inadequate immersion and stirring to hold them to the bath temperature at the low end of the calibration range, followed by heat conducted from the room to the sensor through the mounting stem, and (ii) the ability to now have calibration data at much colder temperatures than what was possible earlier. This combination of factors biased the results at cold temperatures by an amount that varied from calibration to calibration. This became an issue because of the lower temperatures sampled by the GV compared with the C-130, for which the bath calibration techniques were adequate. Re-calibration of the sensors using the bath chamber at EOL's In-situ Sensing Facility (ISF) resolved the bath calibration problem and this calibration data is now applied to projects where the avionics temperature was previously used as a reference.

Variable names for the measurements have also changed. Historically, variables like TTHR1 denoted the direct measurement from the sensors and was referred to as the total temperature. This direct measurement is more accurately known as the recovery temperature so all 'TT' prefixes have been changed to 'RT'. The reason is that air flowing towards the surface of the sensing element may not be decelerated to 0 m/s (which would give the total temperature) but only to a very low air speed (which gives the recovery temperature). Additionally, names have been simplified by removing some of the letters formerly used to denote location so that the variables for the (up to) four heated sensors are RTH1, RTH2, RTH3, and RTH4. The associated ambient temperature variables are ATH1, ATH2, ATH3, and ATH4. RTF1 and ATF1 are used for the recovery and ambient temperatures from the unheated (fast-response) sensors.

King Liquid Water Content

The method for calculating LWC from the King Probe has been revised to include a variety of corrections. The formulas used for the thermal conductivity of air and for relating the Nusselt number to the Reynolds number for heat transfer when out of cloud have been updated. The boiling point of water is now dependent on the pressure and the latent heat of vaporization is now dependent on temperature. Finally, the filtering to give zero LWC values in clear air have been updated, which is especially important for the GV. All of these changes have resulted in a more accurate LWC measurement (PLWCC).

Pressure Corrections

The Laser Air Motion Sensor (LAMS) presented an opportunity to determine the "static defect" (or difference between the true ambient pressure and that delivered by the static-button pressure ports) with reduced uncertainty. The key assumption was that the measurement of dynamic pressure obtained by comparing the pressure at a pitot tube to that at the static buttons is in error primarily because of the error at the static buttons. If that is the case, a prediction of the true dynamic pressure calculated from the LAMS-based airspeed can be used to determine the error in the measured dynamic pressure, and that error (with reversed sign) is also the static defect (Cooper et al, 2014). A parameterized representation of the correction was developed for projects in which LAMS was not involved (which is almost all of them) and is applied to the pressure measurements. This allows for better determination of the longitudinal component of airspeed and a reduction in the uncertainty of wind measurements.

Vertical Winds

Adjustments have been made to the sensitivity coefficients that relate pressure measurements on the radome and at the entrance to a pitot tube to the angle of attack that is used to calculate the vertical wind. An effort was made to find project-wide sensitivity coefficients that produced reasonable measurements of vertical wind for all flights, but for some projects that was not possible and some special steps were taken.

Attack Angle

The ATTACK variable has been updated with revised coefficients for its calculation from the radome pressure-port measurements.

Humidity Mach Number and True Air Speed

Moist-air properties are used to calculate the Mach number and subsequent true airspeed (TAS), resulting in more accurate values. MACHF and TASF now represent the humidity adjusted speeds. The old, dry air calculation is represented by TASDRY. MACHX is set to MACHF and TASX is set to TASF.

VCSEL Humidity

A comprehensive re-calibration of the VCSEL hygrometer over the entire range of water vapor mixing ratio, sample temperature, sample pressure, and laser intensity has been completed. New equations for the three operational modes (1 - 200 ppm, 80 - 3000 ppm, and > 2500 ppm water vapor) were generated which modify the mixing ratio based on the raw measured mixing ratio along with the sample pressure, temperature, and laser intensity. The new calibration improved the overall agreement between the VCSEL and the chilled mirror hygrometers and other humidity-sensing instruments. It also improved the continuity of the reported humidity through mode changes. This resulted in a few percent increase in mixing ratio values in the high humidity mixing ratio mode, a decrease of around 10% in the mid-range mode, and a decrease of around 20% in the low mixing ratio mode. The new calibration is expected to be accurate to 5%, but there is some indication from intercomparisons that for mixing ratios below 50 ppm, the reported VCSEL mixing ratio may be about 10% low.

UHSAS Aerosol Particles

In the UHSAS data processing, the raw sample flow measurement is adjusted to a “corrected” value to determine an equivalent ambient sample volume for the calculation of ambient particle concentration. This correction algorithm had presumed the output of the flow controller to be a *mass flow* measurement requiring correction to standard conditions in order to determine the actual volumetric flow. In fact, the flow controller both controls and reports *volumetric* flow at laser conditions, so the existing adjustment to standard conditions introduced an error that scales roughly with ambient pressure. A new algorithm for calculating the correct flow was developed and results in new concentrations that are roughly unchanged at sea level but are increasingly larger at altitude.

Height Above Terrain

Two variables have been added to the data files. SFC_SRTM represents the height of the terrain under the coordinates of the flight track of the research aircraft. ALTG_SRTM represents the aircraft's altitude above ground along the flight track. Both variables are in meters above the WGS84/EGM96 geoid. Terrain height is determined using data from the Shuttle Radar Topography Mission (SRTM) of 2000, which mapped the altitude of the Earth's surface from 56S to 60N latitude with resolution of 3 arcsec or about 90 m at the equator. For the US and territories, the resolution is 1 arcsec or about 30 m. The measurement uncertainty is about 9 m at 90% confidence, but there are some biases. The SAR-radar technique did not penetrate fully through vegetation and so might reflect the top of the vegetation canopy or some level intermediate between the canopy and the surface. The radar also penetrated a few meters into snow and so measured a height between the snow cover and the terrain (as measured in Feb. 2000). There are also some gaps, especially in mountainous areas.

When there is no terrain but only ocean, terrain height has been set to zero. Remaining missing-value regions after interpolation to fill small gaps are mostly over ocean and are replaced by zeros as well.

Section II - Project and Individual Flight Summary

The following comments apply to the entire project.

- All temperatures are based on new coefficients. ATF1 is selected as the primary temperature (ATX).
- EW_VXL is the primary water vapor measurement (EWX) for all flights and feeds into the primary dewpoint measurement (DPXC).
- A satisfactory solution for calculating a consistent WIC for these flights could not always be found due to variation in the sensitivity coefficients from flight to flight. Even though WIC is good in most cases a low-pass filter has been applied to correct the vertical wind measurements. WIF is the new variable representing these corrected measurements. WIX has also been added as the primary vertical wind and is set to WIF for all flights.
- The coincidence correction previously applied to the Water CN Counters was found to be specific to RAF's butanol CN counter. For this reprocessing, a proper coincidence correction has been applied. The change becomes apparent only at high concentrations, with new values exceeding the old, and increasingly so toward higher concentrations. Both WCNs had, independently of each other, occasional flow departures from their specified control values. Each also saw brief periods of very low or zero particle counts. The causes for these problems remain unknown, and these periods have been blanked in the data file. The length of sample line for the WCNs introduces a delay of about 1 second in their measurement time series, as determined by comparisons with the wing-mounted UHSAS. The WCN data are shifted by 1 second.

Not all flights have significant changes beyond what is described above. Only the flights with large differences from the previous dataset are referenced below.

RF02

On approach, from about 20:53:40 to 20:54:15, the aircraft encountered unusually high ultrafine particle concentration. CONCN_DB, from the WCN without the diffusion battery at that time, saw concentrations in excess of 1e6/cm^3. Such extreme values are beyond the capacity of the instrument, and the correction for particle coincidence in the detection volume becomes both very large and highly uncertain. These data should be regarded as qualitative rather than quantitative.

RF04

The UHSAS laser was unstable for a period of about 3.5 hours (13:53 - 17:16), and no valid data were obtained during that time.

RF07

The UHSAS laser was unstable for a period of 47 minutes stretch (19:43 - 20:30), and no valid data were obtained during that time.

RF09

During this flight there were many instances, mostly brief, of laser instability leading to loss of UHSAS data. Stitching errors between gain stages also were more frequent and severe than on other flights.

RF11

UHSAS data were not recorded for more than thirty minutes into the flight. The reason for this remains unknown.

RF13

The UHSAS laser operated in a bad mode for all but the last twenty minutes of flight. No valid data could be recovered.

References:

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