Appendix to HIPPO-I 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 HIPPO-I. 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.

Dewpoint Sensor Cavity Pressure

After pressure sensors were installed in the housings for the dew-point sensors, it became evident that the pressure in those housings differed significantly from ambient pressure and that this led to errors in the reported dew-point measurements. A parameterized representation of the pressure in the housing was developed that is now applied and corrects the measurements.

Humidity Variables

Vapor-pressure calculations are now based on the Murphy and Koop (2005) formulas, which have updated previous methods to improve the calculation of vapor pressure at very cold temperatures. New equations for the equilibrium vapor pressure over a plane water surface and over a plane ice surface have been added, resulting in more accurate humidity measurements.

There have also been some changes to the variable names and to the meaning of some variables. The water vapor pressure variables (EWX, EW_DPR, EW_VXL, etc.) are the partial pressures of water vapor, and the dewpoint variables (DP_DPL, DP_DPR, DP_VXL, etc) are the dewpoint temperatures at which the ambient water vapor pressure would be in equilibrium with a plane water surface in the absence of dry air (i.e., without the "enhancement factor" that affects sensors measuring the dewpoint or frostpoint). As a result, the dewpoint variables differ slightly from the recorded mirror temperatures (MIRRTMP_DPR, MIRRTMP_DPL). In addition, corrections are made for the difference in pressure in the dewpoint sensor housing vs ambient pressure (see above), using either direct measurements of the pressure in the housing or, for projects before there was a direct measurement of pressure, an empirical representation of the housing pressure based on later projects where the measurement was available.

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.

An additional issue pertains to the variable WI, which historically has been based on vertical speed (VSPD) from the INS. In the INS itself, this variable is updated to the pressure altitude, so in a baroclinic atmosphere there are false vertical motions in this variable that don’t represent real changes in geometric altitude. For that reason, we have now changed to use of VSPD from the GPS receiver. However, if the GPS information is missing, that leads to WIC missing. A new variable “WIR” is included for these times. WIR uses ROC (rate of climb), which is based on VSPD with a correction for the difference between pressure and geometric altitude. It is usually in good agreement with WIC when both are available.

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.

Pressure Altitude

The formula used to calculate the pressure altitude (PALT) was updated to use the International Standard Atmosphere. The resulting changes in PALT are at most +/- 5 m but are now consistent with international aviation standards.

Equivalent Potential Temperature, Virtual Temperature, and Virtual Potential Temperature

The previous formulation of equivalent potential temperature (THETAE), based on a formula from Bolton, has been replaced by a new formulation by Davies-Jones that is more accurate. Derived variables for wet-equivalent potential temperature have also been added. The new variables are named THETAP and THETAQ for, respectively, the pseudoadiabatic equivalent potential temperature and the wet-equivalent potential temperature. If no measurement of liquid water content is available, then THETAQ is not included.

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.

2D Probe Processing

A new algorithm has been used to process the data from the 2D probes (2DC and 2DP) and produce new variables in the files. The new variables are identified by the text "2D" in the names. This is followed by two more letters, a "C" or "P" for 2DC or 2DP and then an "A" or "R". "A" represents all counted particles while "R" represents only those that are identified as round. The "round particle" population is intended to represent liquid water particles. The "all particle" population follows the more traditional method of processing 2D image data, placing both round and irregularly shaped particles together into the same particle size distribution.

Particles are sized using the circle-fit method. It simply fits the smallest possible circle around a particle image and uses the diameter of that circle as the diameter of the particle. This method is used for its computational efficiency, as well as its ability to produce a clean comparison of the area of particle to the area of the circle. This area ratio is used for subsequent particle rejection, roundness detection, and may also be used for computing such parameters as fall velocity and optical extinction.

Large particles that impact on the forward surface of a probe arm can break into many pieces and then be imaged by the 2D probes. This results in an overestimate of the concentration of small particles. Since these small particles appear in clusters, the time between neighboring particles, or interarrival time, may be used to detect suspected shattering events. The new algorithm corrects for these shattering events.

The particle rejection criteria in the software serve two purposes, to distinguish between “round” and “all” particles, and to remove image artifacts. Image artifact rejection is simply based on the ratio of the measured area of a particle (after holes are filled) to the area of the smallest circle that can enclose that particle. If this ratio falls below a certain threshold, the particle is rejected. Distinguishing between “round” and “all” particles is done in a similar manner, with the area ratio requirement raised to eliminate particles that do not meet a certain roundness.

Section II - Project and Individual Flight Summary

The following comments apply to the entire project.

- All temperatures are based on new coefficients. ATH1 is selected as the primary temperature (ATX).
- EW_VXL is the primary water vapor measurement (EWX) for RF01 - RF07 and feeds into the primary dewpoint measurement (DPXC). VCSEL was inoperable for RF08 - RF11 so the variable H2OMR_GMD is used as the primary water vapor measurement for these flights.
- Frequent detector noise produced spurious particle counts in the small-diameter size bins of the UHSAS. It was necessary to discard the first seven bins, setting the effective lower bound of the UHSAS to 90 nm. Two other errors in the processing algorithm for bin consolidation were found and corrected. One caused a section of the concentration histogram from smaller diameters to repeat through larger diameters in place of the actual data. The other error assigned an erroneous low value to the upper consolidated bin at 493-608 nm. These corrections significantly improve the histograms.

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

RF02
PLWCC is blanked out 21:24:40 - 21:25:05, 22:16:18 - 22:18:54, and 23:44:00 - 23:45:04.
WIC has a negative bias near the end of the flight and should be used with caution.

RF03
PLWCC is blanked out 20:12:00 - 20:32:10 and 21:01:40 - 21:06:25.

RF04
PLWCC is blanked out 19:52:55 - 19:55:40.
From 24:11:00 to 24:27:50, there are multiple segments that show DP_VXL higher than temperature. This may be temperature sensor wetting, but even in clear regions DP_VXL seems to be high.

RF05
QCR is blanked out 23:57:00 - 24:12:00.

RF06
SSLIP has been blanked out 25:36:00 - 25:57:00 because of spikes affecting WDC.

RF07
VCSEL dewpoints are too high in some areas, similar to RF04.

RF08
The wind blankout has been extended to 27:20:00.

RF09
PLWCC is blanked out 07:32:38 - 07:33:43.

RF11
PLWCC is bad for the entire flight and has been removed.

References:

Murphy and Koop (2005): Review of the vapour pressures of ice and supercooled water for atmospheric applications. *Q. J. R. Meteorol. Soc.*, **131**, 1539–1565.

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