**Description of Wband radar data processing programs from NOAA P3 aircraft during ATOMIC**

**Version `**

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This document describes various matlab scripts used to process Wband data taken from the NOAA P3 during the ATOMIC field program. These programs are intended to form the basis of further processing to produce new files corrected for attenuation and aircraft motion. Initially the plan is to write new moment files. The moment files currently consist of time-range matrices of reflectivity, Doppler velocity, Doppler width, and SNR in hourly nc files. There are 220 range gates from 0.21 to 7.05 km.

We need to do some processing to make the data more useful.

Stage 1: Add two more time-range matrices: 1) reflectivity corrected for oxygen/nitrogen and water vapor attenuation, 2) Doppler velocity corrected for aircraft pitch/aircraft TAS.

Stage 2: Create a new set remapped to fixed altitude coordinates (0-7.5 km). Likely this would be the same 5 matrices as Stage 1.

Stage 3: Add an additional matrix containing reflectivity corrected for rain attenuation.

I have generated several matlab scripts that are major steps for stages 1 & 2.

*WbandPlot\_P3\_atomic2020\_basic\_3.m*

This is my main wband processing program. It is set up to analyze a selected flight by inputting day number (017, 019, etc; note, the input is text so you should include the leading zero). Each flight has a number of hours of data (see Table 1). You can select just one hour or subintervals but I usually select the entire range to process the whole flight. This script uses various other scripts that I have attempted to include in the directory.

The program reads in the aircraft flight level data for the flight and computes profile averages.

Then, it reads in each hourly file and does graphics and processing. For selected variables it appends each hourly file to create an all flight file (usually with ‘h’ or ‘m’ added to the variable name). Some processing is done at hourly intervals and some is done on all flight variables. Sorry about that but this is and old program that has been evolving like cancer.

This program has one section that uses aircraft altitude to remap moments to a fixed altitude grid (238 altitude gates 0.21-7.56 km). The matrix is initially filled with NaN’s and then the range gates are flipped and inserted. When the aircraft altitude exceeds 7.05 km, there are NaN’s left in the matrices at height below 7.56-altitude.

There is a lot of processing done to aid in visualizing the data and to create level2 products such as normalized radar cross section (nrcs), cloud top height (httm), or cloud-nocloud indices. At the program writes a level2 file called ‘cloudsum’ that is described in the readme file P3\_TimeSeries\_readme\_ATOMIC\_2020\_v2.docx. Most of this processing could be eliminated from the program and useful information could be introduced by reading the cloudsum file.

The flight level data is used for a lot of the processing. These files were produced from the original AC.nc aircraft files. The nc files were read in and certain variables useful for radar were abstracted and saved as mat files. The mat files are now read in by the radar processing program. Atmospheric profile information is needed for various purposes including navigation, altitude, pitch/roll, plus temperature, pressure, humidity, wind speed/direction. The T, q, P will be required for molecular/water vapor attenuation. The windspeed/direction could be used for Doppler correction. Instead of using profiles from the aircraft systems, we could read in the dropsondes for each flight and use them (a simple average profile or interpolate between profiles). There are roughly 30 sonde profiles per flight, so the sampling is better than the limited aircraft profiles. There is a mat file with all dropsondes for each flight (see Dropsonde\_readme\_ATOMIC\_2020\_v1).

Molecular/water vapor attenuation scripts have been written. One function script that computes the attenuation coefficients given inputs of height, temperature, mixing ration, pressure, and radar frequency - *attenCalc(z,t,q,p,f).* A second script, *rho\_prof\_atomic,* reads in the sondes for a selected flight, computes a mean thermodynamic profiles, and uses *attenCalc* to get the mean profile of attenuation coefficieent. For a given aircraft altitude, it computes the profile of integrated attenuation correction and precipitable water as a function of range below the aircraft (see Fig. 1). For every aircraft altitude, there is a range-dependent attenuation correction. It might be possible to develop a simple parameterization or a look-up table as an alternative to computing the profiles 50,000 time per flight.

 Corrects for attenuation by rain are described in Fairall et al., 2018.

Fairall, C., S. Y. Matrosov, C. R. Williams, E. J. Walsh, 2018: Estimation of rain rate from PSD airborne Doppler W-band radar in CALWATER2. *J. Atmos. Oceanic Tech*., **35**, 593-608. DOI: 10.1175/JTECH-D-17-0025.1.

These are based on the Hitschfield-Bordan solutions to the attenuation equation. The key is the use of a formula relating the attenuation coefficient to reflectivity.



One solution relates the corrected reflectivity, *Ze,* to the measured, *Zem*,



Where h is the range and





Where the boundary condition is that *Zem*(0)=*Ze*(0). This solution tends to get worse as range increases and *qS* approaches 1. For downlooking airborne radar, a solution that is better behaved uses the boundary condition at the surface based on knowing the normalized radar cross section (*nrcs*).





There is code to do these calculation is buried in the program *wband\_dbzProf\_wsra\_4\_020619\_post.m*. It is designed to be run **after** the *WbandPlot\_P3\_* program. It was developed on the CALWATER2 data and has not been tried with the ATOMIC program. Note, the corrections are only a small part of this program. Another approach is to use the x-band TDR radar, which is essentially unattenuated at moderate rain rates. Code for doing some of this is in the program *xband\_P3\_raw\_data.m*. This program reads previously saved processed data from the wband and data from the xband (nadir part of the cone only). The xband calibration is checked by finding the surface return xband nrcs (should be about -3 dB for xband at 20 deg incidence angle). There is also some unfolding of the Doppler. This shows that the corrected wband and the xband are in good agreement. So, in principle xband reflectivity could be used to correct wband reflectivity. This program contains comparisons of W and X band reflexctivity and Doppler. Xband is fairly close to ideal Rayleigh. See the short writeup W-band Moments and Rain Rate for some discussion.

Just for fun, the program *wbandSpectrum\_gauss\_sim\_4.m* is included. This program simulates the Doppler spectrum produced by spectrally processed radar and duplicates the computation of the three moments found in the Wband moment files. It was used in creating most of the graphics in the writeup *Wband\_Turb&MIcrophysics\_specWidth2b.docx.*

Table 1. Summary of P3 flights for ATOMIC. The lat/lon for the center of the dropsonde is nominal and applies to one of the circles. Cfract refers to the average cloud fraction as determined form the downlooking IR sensor. It is approximate and misses a lot of small clouds.





Figure 1. Sample profile of reflectivity attenuation correction (dB) and precipitable water as a function of altitude for aircraft at an altitude of 5 km.