Installation, Operation and Troubleshooting Guide for MWR.EXE: Software for ARM Microwave Water Radiometers

Software version 4.12
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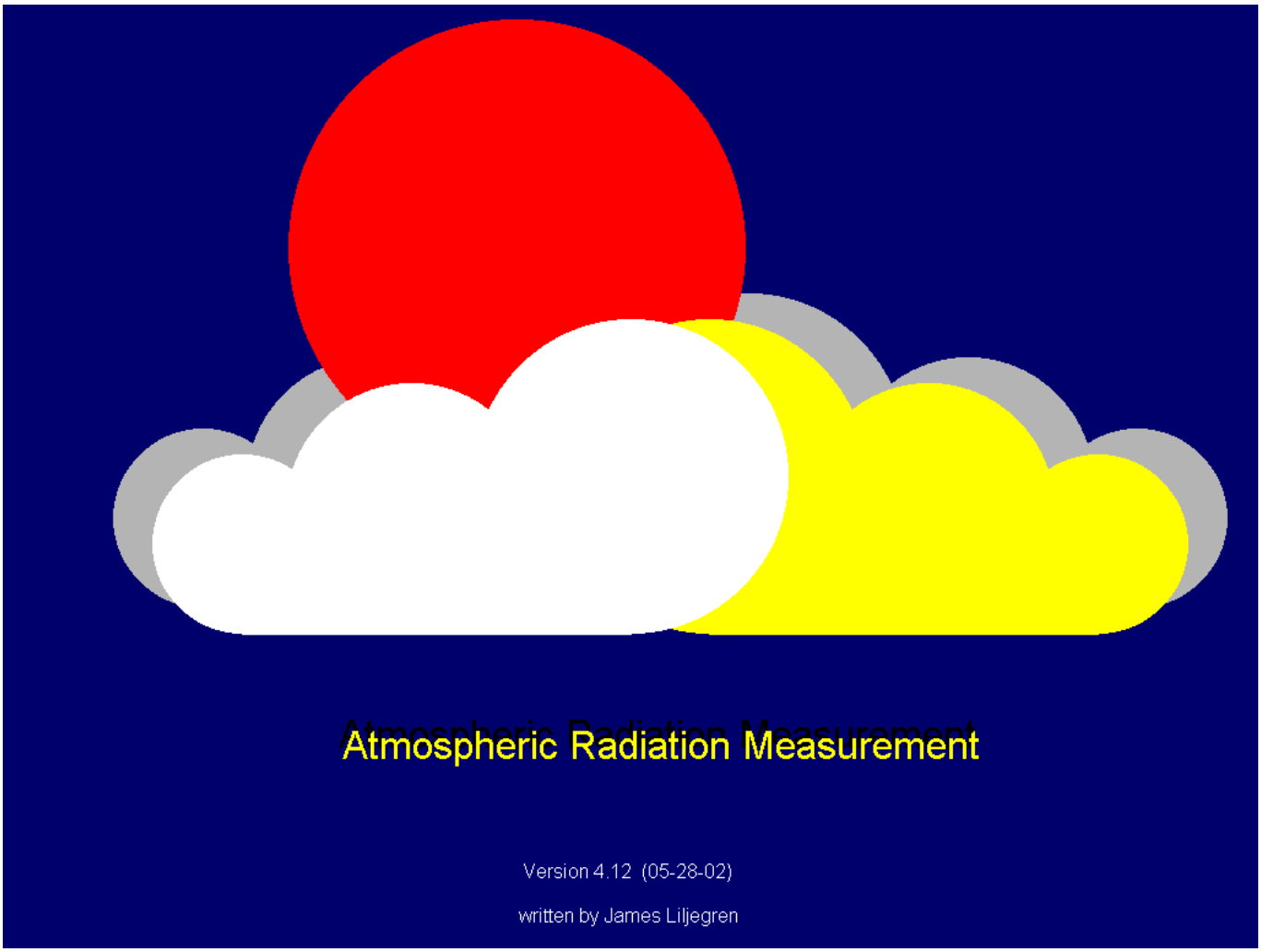

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1. Overview

This program controls the microwave water radiometers (MWRs) built by Radiometrics Corporation for the Atmospheric Radiation Measurement (ARM) Program. It permits the user to make measurements along a single line-of-sight, specified by azimuth and elevation angles, or to scan the sky by varying the elevation angle. The software processes the signals provided by the radiometer - applying calibration, beamwidth and pointing offset corrections, and retrieval algorithms - to provide measurements of the total water vapor and, for cloudy conditions, total cloud liquid water in the field of view of the instrument. It can also use the results of the sky scans to update its calibration automatically.

Additional details about the operating modes and the automatic calibration procedure are provided in appendices.

1.1 Required system hardware and software

This program was compiled from its FORTRAN source code to run on a computer with an Intel Pentium processor running Microsoft Windows 98 second edition. Although the program has been tested on this configuration only, it may also work on more recent versions of Windows.

The graphical displays have been developed for use with a VGA adapter and color monitor.

1.2 Expected user computer skills

This documentation assumes that the reader is familiar with the Windows operating system. Persons not familiar with this operating system should refer to the documentation supplied with it for further information as needed. In particular, the following familiarity is required:

- starting and shutting down the computer properly;
- creating directories and copying files from a diskette;
- editing simple text files.

2. Installation and Setup

2.1 Installing the software

Prior to installation, two directories should be created. First create a directory where the MWR.EXE program and its auxiliary files will be installed. For the purposes of this documentation, this directory is assumed to be **c:\mwr**. Then create a directory where the data files will be saved. For the purposes of this documentation, this directory is assumed to be **c:\send_dir**.

To install the software, insert the distribution diskette into the diskette drive and copy the file MWR.EXE to the installation directory c:\mwr. If you are not upgrading from a previous version of MWR.EXE, also copy the files MWR.CFG and MODE to c:\mwr.

A brief description of these files, as well as other files created by the MWR.EXE program in the course of operation is provided in an appendix.

2.1.1 Upgrading from MWR.EXE version 3.xx

Files MWR.CFG, MODE, ND_CALIB.LOG, and OFFSET.LOG created by previous versions of the MWR.EXE program are fully compatible with version 4.12 and may be retained. The font file HELVB.FON is no longer needed and may be deleted.

2.2 Configuring the software

Once the directories have been created and the files have been installed, the next step is to configure the software. Two files contain user-supplied information that governs the operation of the instrument, MWR.CFG and MODE. These are the only two files that should be modified by the user. The MWR.EXE program reads these two files at startup and shortly after a new data file is created. They may be modified without interrupting and restarting the program.

2.2.1 MWR.CFG file

The configuration file is divided into nine sections: radiometer identification, computer configuration, calibration, TIP configuration, LOS configuration, retrieval, warm-up, plotting, and IR thermometer. Most of the parameters in the MWR.CFG file are common to all ARM MWRs and have been preset. Only a few parameters will need to be set when the software is installed. These include the MWR serial number and, if installed on the MWR, the serial number of the IR thermometer. In addition, the default calibration and temperature correction coefficients will need to be set to match the instrument.

The structure of the MWR.CFG file and an example file are provided in appendices.

CHANGE FROM PREVIOUS VERSION: The serial communications baud rate is now user selectable (1200 or 9600 baud) in the computer configuration section of the file. For compatibility with pervious versions of the MWR.CFG file, if the baud rate line is missing the program assumes 9600 baud.

2.2.2 MODE file

This file is comprised of a single entry: “LOS”, “TIP”, “DIAG” or “EXIT”. Accordingly, the radiometer will be operated in either line-of-sight (LOS), tip curve (TIP), or diagnostic (DIAG) mode or it will be shutdown and the program will exit.

A description of each operating mode is provided in an appendix.

3. Operation

3.1 Starting the program

Double-clicking on the program icon with the mouse will start the program. Alternatively, the program can be set to start when the computer is (re)started. Refer to “startup, running programs at” in Windows Help on your computer.

3.2 Interrupting/stopping the program

To stop the program, change the entry in the MODE file to read “EXIT”. If the graphical display is not enabled, a single CTRL-C entered at the keyboard will cause the program to close the current data file and read the MWR.CFG and MODE files; if the graphical display is enabled, CTRL-C will have no effect. If an emergency arises the program may be terminated by typing ALT-F4. This will result in an incomplete data file in the C:\MWR directory (with the extension .TMP). The program will rename this file and move it to the data directory the next time it generates a complete data file.

3.3 Changing operating modes

To change modes, change the entry in the MODE file to the desired mode. The program will read this file when next it creates a complete data file (typically on the hour). If the change needs to be effected sooner, and if the graphical display is not enabled, a single CTRL-C entered at the keyboard will cause the program to close the current data file and read the MWR.CFG and MODE files; if the graphical display is enabled, CTRL-C will have no effect.

3.4 Understanding the displays

When the program is first started, the ARM logo is displayed for five seconds. If it was enabled in the MWR.CFG file, the graphical display is initialized; otherwise the text-only display is used.

3.4.1 Text-only display

If the graphical display is disabled, text messages will be printed to the display to indicate the current status of the radiometer. These will have the following format:

```
<date> <time> <message text>
```

where the date 020813 indicates 13 August 2002, and the time 164249 indicates 16:42:49.

In addition to the status messages, summaries of the latest INITialization, TIP, LOS, or DIAGnostic results will be displayed with the following formats:

```
INIT date time wet_window tknd tkxc tkbb tkair
```

```
LOS date time wet_window tknd tkxc tkbb tkair
    date time vapor liquid tbsky23 tbsky31 ir_temp
    (the second line is repeated for additional sky observations)

TIP date time wet_window tknd tkxc tkbb tkair
    date time vapor liquid tbsky23 tbsky31 ir_temp
    date time vapor liquid tbsky23 tbsky31 ir_temp (usually two LOS per TIP)
    date time n_tip_angles tnd23i tnd31i r23 r31

DIAG date time wet_window tknd tkxc tkbb tkair tnd23 tnd31 bb23 bb31 bbn23 bbn31

where  date = year month day (02 08 13 = 13 August 2002)
       time = hour minute second 1/100ths
       wet_window = 1 (moisture detector ON) or 0 (detector OFF)
       tknd  = noise diode mount temperature (K)
       tkxc  = mixer temperature (K)
       tkbb  = blackbody temperature (K) (average of 2 sensors)
       tkair = ambient temperature (K) (only on units 20 and 21)
       tnd23 = noise injection temperature (at 23.8 GHz) adjusted to tkbb
       tnd31 = noise injection temperature (at 31.4 GHz) adjusted to tkbb
       bb23  = signal (counts) at 23.8 GHz viewing blackbody (noise diode OFF)
       bb31  = signal (counts) at 31.4 GHz viewing blackbody (noise diode OFF)
       bbn23 = signal (counts) at 23.8 GHz viewing blackbody (noise diode ON)
       bbn31 = signal (counts) at 31.4 GHz viewing blackbody (noise diode ON)
       vapor   = integrated water vapor along line-of-sight (LOS) path (cm)
       liquid  = integrated liquid water along line-of-sight (LOS) path (cm)
       tbsky23 = sky brightness temperature at 23.8 GHz (K)
       tbsky31 = sky brightness temperature at 31.4 GHz (K)
       ir_temp = temperature reported by IR thermometer (K)
       tnd23i = noise injection temperature at 23.8 GHz derived from this tip (K)
       tnd31i = noise injection temperature at 31.4 GHz derived from this tip (K)
       r23    = correlation coefficient for 23.8 GHz regression
       r31    = correlation coefficient for 31.4 GHz regression
```

3.4.2 Graphical display

An example of the graphical display is presented in Figure 1. The display is divided into five parts: the status display, the message display, the temperature plot, the total or "precipitable" water vapor (PWV) and liquid water path (LWP) plot and (in TIP mode only) the tip curve plot.

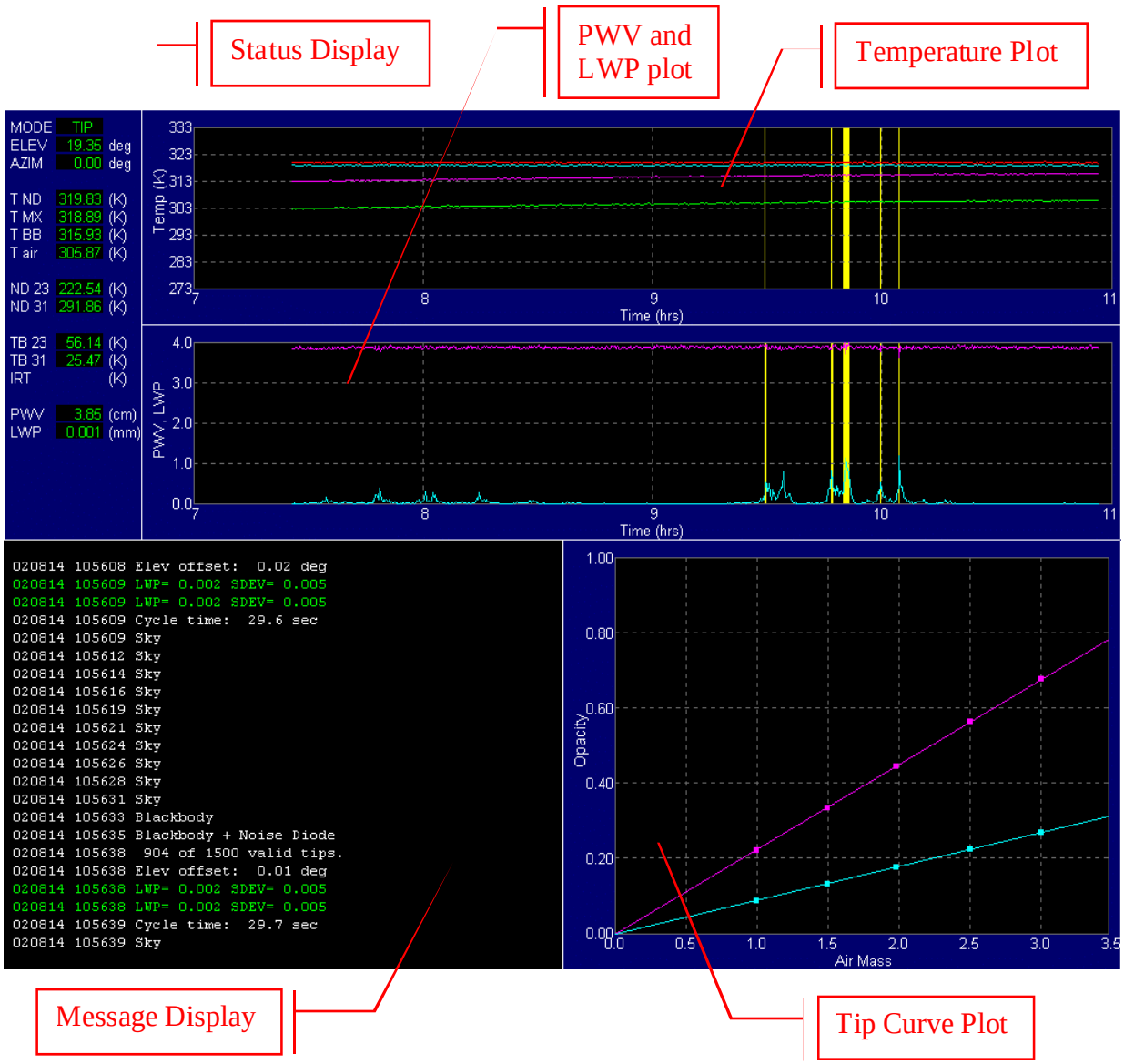

Figure 1. The graphical display is comprised of the status display, the message display, a temperature plot, a plot of the retrieved PWV and LWP, and (in TIP mode) a plot of the latest tip curves.

The message display is very similar to the text-only display: it presents the status, warning and error messages generated by the software along with the date and time they were generated. Status messages are in white text. Green text indicates the successful result of a particular operation, such as a test for communication with the radiometer. Yellow messages indicate a warning condition that

the software will attempt to fix. For example, if the ND_CALIB.LOG file is missing, the software will note this in a yellow message and will attempt to create this file. As another example, if the program loses communication with the radiometer a yellow message will inform the operator of the problem and the program will attempt to re-establish communications. If a fatal error is encountered then a message will be displayed in red text. The message will also be written to an error file and moved to the data directory (usually C:\SEND_DIR); the program will then shut down the radiometer and exit. Examples of fatal errors are an inability to create ND_CALIB.LOG and an inability to re-establish communication with the radiometer after repeated attempts.

The status display shows the current value of important parameters. These are normally displayed in green letters on a black background. Under certain conditions they will be displayed as black letters on a yellow background (warning) or white letters on a red background (error). The top group of three values in the status display shows the current mode, elevation and azimuth angles. When first started, the mode will indicate "START" until the software determines that the radiometer has thermally stabilized. Once stabilized, the mode will reflect the contents of the MODE file unless the auto-calibration feature has overridden it and put the radiometer into TIP mode. The elevation angle will change to indicate the current pointing direction; a value of -90 indicates that the mirror has been rotated downward to view the blackbody target.

The next group of four values indicates the current temperature of the noise diode (ND), mixer (MX), blackbody (BB) and, if installed, the outside air. The outside air sensor is only installed on radiometers with serial numbers 20 and higher. If the air temperature sensor is not installed, no value will be displayed.

The next group of two values includes the noise injection temperatures. In LOS mode these are the values actually used to produce the brightness temperatures (i.e. adjusted to current blackbody temperature) whereas in TIP mode these are the values returned by the latest tip curve. If the correlation coefficient from a tip curve is less than the minimum acceptable (i.e., cloudy sky conditions), then these values will be displayed as black letters on a yellow background.

The next group of three values includes the brightness temperatures at 23.8 and 31.4 GHz and the IR thermometer temperature, if installed. If the moisture detector mounted on top of the radiometer is triggered, then the brightness temperatures will be displayed in black letters on a yellow background; if the PWV is less than zero, then the brightness temperatures will be displayed in white letters on a red background to indicate an error.

The last two values are the total or "precipitable" water vapor (PWV) and the liquid water path (LWP) derived from the measurements. If the moisture detector mounted on top of the radiometer is triggered, then the PWV and LWP will be displayed in black letters on a yellow background; if the PWV is less than zero, then the PWV and LWP will be displayed in white letters on a red background to indicate an error.

CHANGE FROM PREVIOUS VERSION: If the radiometer is in LOS mode, the values of PWV and LWP are derived from brightness temperatures calculated using the calibrated noise diode (i.e., the noise injection temperatures). In TIP mode, PWV and LWP are derived directly from the tip curve results.

The temperature plot provides a graphical depiction of the time history of the temperatures of the noise diode (red), mixer (cyan), blackbody (magenta) and, if installed, the air (green). If the moisture detector on top of the radiometer is triggered, a yellow vertical band will be displayed behind the temperature traces. The range of temperatures plotted is defined in the MWR.CFG file. The time axis automatically scales.

The PWV and LWP plot provides a graphical depiction of the time history of the total vapor (magenta) and liquid water (cyan) amounts. Note that the units for PWV are cm whereas the units for LWP are mm. If the moisture detector on top of the radiometer is triggered, a yellow vertical band will be displayed behind the traces. The range of vapor/liquid plotted is defined in the MWR.CFG file. The time axis automatically scales.

When the radiometer is in TIP mode, the latest tip curves at 23.8 (magenta) and 31.4 GHz (cyan) are plotted. All of the data points will fall on or very near to the regression line if the tip curve is valid. In this case (i.e., the correlation coefficient of the linear regression is greater than the minimum specified in the MWR.CFG file) the symbols are filled in; otherwise, if the tip curve is not valid, the symbols are hollow. If a problem occurs with a tip curve (e.g. when it is raining), the color of the symbols and regression line will change to yellow.

4. Appendices

4.1 Error messages and troubleshooting

The most common problems with the microwave radiometer are associated with the serial communications. If the warning messages do not become fatal errors, it is likely that a connector has become loose or needs cleaning; alternatively, long copper cables can be subject to EMI during electrical storms or if placed too close to power cables. If communications are lost altogether, a cable may have become disconnected, power to the radiometer may have been lost, or a serial hardware failure may have occurred.

A terminal emulator program, such as HyperTerminal included with Windows 98, is useful in debugging serial communications problems. The serial interface should be set to 9600 baud, 8 bits, 1 stop bit, no parity, no handshake, no flow control. When the radiometer is first powered up, it will send out the following message out the serial port:

```
Radiometrics WVR Rev 1.2A - 9600
0.0V= 63.00000
10.0V= 61838.00
Initialization Complete
OK
```

(The number of counts that correspond to 0 and 10 volts may not match the above values exactly.)

To check whether the radiometer is receiving and responding to commands, a status- or S-command may be sent by typing an “s” and a linefeed (Ctrl-j); the radiometer should respond “READY”.

A list of error messages, organized by severity and function, along with their meanings and suggested remedial actions, is provided in the following table.

Message	Meaning / Corrective Action
Informative Messages	
Startup	
"Software v. 4.12 last revised 05-28-02"	Version and revision date of MWR.EXE.
"WILL SIMULATE RADIOMETER"	The program will simulate the outputs of a real radiometer. Effected by setting the serial number to 000 in MWR.CFG.
"Checking for thermal stabilization."	Checking that the noise diode and mixer have warmed up.
"Radiometer is NOT thermally stable."	The noise diode and mixer have not warmed up.
"Radiometer is thermally stable."	The noise diode and mixer have warmed up.
Calibration	
"Restart detected; will check calibration."	Whenever the MWR.EXE program is restarted, the calibration is checked.

"Loading calibration data from ND_CALIB.LOG"	If autocalibration is enabled, prior tip data will be loaded from this file.
"...xxxx lines loaded."	Prior tip data successfully loaded from ND_CALIB.LOG.
"Using default calibration."	The calibration in MWR.CFG is being used. Either ND_CALIB.LOG does not exist or it does not contain any valid calibrations.
"Resuming calibration check..."	An old data file was closed and a new one created while the program was acquiring tip data to check the existing calibration.
"Resuming calibration update..."	An old data file was closed and a new one created while the program was acquiring tip data to update the existing calibration.
"Initiating calibration check..."	If the mode is set to LOS and autocalibration is enabled and the current calibration is out of date, then the mode will be set to TIP and the calibration will be checked.
"The current calibration is still valid."	The new calibration data are within the specified tolerance of the current calibration.
"The calibration has been updated!"	The new tip data have been processed and the old calibration has been replaced.
"xxx of yyyy new tips."	Indicates progress toward acquiring the number of new tips necessary to check the calibration.
"xxx of yyyy valid tips."	Indicates progress toward acquiring the number of valid tips necessary to update the calibration.
"Creating a new ND_CALIB.LOG file."	If the ND_CALIB.LOG file does not exist, it will be created to accept the tip results.
RS-232 Communication	
"Simulating radiometer communication." "Communicating with radiometer."	The program is simulating a radiometer. Communications with the radiometer have been established.
"Receiving OK"	Communications with the radiometer have been re-established.
Radiometer status	
"Initializing the radiometer."	Diagnostic mode; an I-command has been issued.

"31.4 GHz Gunn ON."	Diagnostic mode; the 31.4 GHz Gunn diode local oscillator has been turned on.
"23.8 GHz Gunn ON."	Diagnostic mode; the 23.8 GHz Gunn diode local oscillator has been turned on.
"Gunns OFF."	Diagnostic mode; both local oscillators have been turned off.
"Noise diode ON."	Diagnostic mode; the noise diode has been turned on.
"Positioning elevation mirror."	Diagnostic mode; an E- or F-command has been issued to position the elevation angle.
"Positioning azimuth."	Diagnostic mode; an A-command has been issued to position the azimuth angle.
"Blackbody"	The elevation mirror has been rotated downward and measurements of the blackbody target are being made.
"Blackbody + Noise Diode"	With the elevation mirror rotated downward and the noise diode energized, measurements of the blackbody are being made.
"Sky"	The elevation mirror has been positioned upward and measurements of the sky are being made.
“Cycle time: nn.n sec”	The time in seconds required to complete the LOS or TIP observing cycle.
"CTRL-C has been typed. Aborting LOS."	Acknowledges that a CTRL-C has been typed. Does not work in graphics mode.
"CTRL-C has been typed. Aborting TIP."	Acknowledges that a CTRL-C has been typed. Does not work in graphics mode.
"Time to close this data file."	The pre-arranged time to begin a new data file has arrived.
"Close this data file, read MODE file."	A CTRL-C has been typed; the current data file will be closed, the MWR.CFG and MODE files read, and a new data file will be started.
"Shutting down."	The mode has been set to EXIT; the radiometer will be shut down and the program will exit.

"Pointing mirror at blackbody."	Part of shut down procedure.
"Turning off Gunns and noise diode."	Part of shut down procedure.
"Closing serial port."	Part of shut down procedure.
Warning Messages	
Startup	
"Warm up aborted; invalid data may result."	A CTRL-C has been typed during warm-up which causes the program to begin taking data even though the radiometer is not warmed up. Does not work in graphics mode.
"Cannot find MODE file...assuming TIP mode."	If the MODE file does not exist it will be created and the mode set to TIP.
Calibration	
"Calibration is out of date."	If autocalibration is enabled, the program will compare the date of the calibration with the current date. This indicates that the calibration is older than specified in the MWR.CFG file.
"Cannot open file ND_CALIB.LOG."	Occurs when attempting to open the file to load the calibration. The file may not exist.
"Cannot read file ND_CALIB.LOG."	Occurs when attempting to load the calibration from the file.
"Using default calibration."	If ND_CALIB.LOG does not exist or cannot be read, the calibration in the MWR.CFG file is used.
"A calibration shift has been detected!"	A check of the current calibration shows that it is no longer valid.
"Unable to open file ND_CALIB.LOG: xxxx"	Occurs when attempting to open the file to store tip results. The program will attempt to create the file.
RS-232 Communication	
"COMM buffer overflow..."	Garbled communications. The buffer will be cleared and the command re-tried.
"Radiometer not responding..."	The radiometer did not respond to a serial command. (subroutine RECEIVE)
"Radiometer not responding, still trying..."	The radiometer did not respond to a serial command; the command will be retried. (S-command.)
"Re-trying..."	The radiometer did not respond to a serial

	command; the command will be retried. (I-, Z-, R-, E-, F-, and A-commands.)
Radiometer status	
"IR temperature out of range."	The infrared sky temperature is less than the minimum detectable by the IR thermometer.
"Error copying data file."	An error occurred while copying a .TMP file to the data directory.
"Error copying ERROR log."	An error occurred while copying a .ERR file to the data directory.
Fatal Errors	
Startup	
"Radiometer will not thermally stabilize!"	The noise diode and mixer temperatures did not meet the stabilization criteria in the MWR.CFG file in the allotted time. *Check that the criteria are not too stringent and that the time allotted is sufficient.*
"Invalid MODE file entry. Quitting..."	If the mode is not recognizable, then EXIT is assumed. Edit the MODE file.
"Cannot create MODE file. Quitting..."	Perhaps the disk is full?
"Cannot read MODE file. Quitting..."	Delete the MODE file and create a new one.
“Error: cannot set graphics mode”	The computer does not have a VGA adapter. Edit the MWR.CFG file to disable the graphical display.
Calibration	
"Failed to open file ND_CALIB.LOG"	The file could not be opened to store new tip results. Perhaps the disk is full?
"Unable to read file ND_CALIB.LOG: xxxx"	The file is unreadable. Delete the MWR.CFG file and restart the program.
RS-232 Communication	
"Could not open serial port. Aborting."	The serial port may not exist; check that the correct comm port is given in MWR.CFG. Otherwise a hardware problem may exist.
"Radiometer not responding."	Communication with the radiometer could not be established after repeated trials. Check the serial data lines. A terminal emulator program may be used for this purpose. Cycling the power to the radiometer will normally clear the serial port.

"Giving up."	Same as above.
"Unexpected response to I-cmd; giving up."	Garbled communications. Cycling the power to the radiometer will normally clear the serial port.
"Unexpected response to Z-cmd; giving up."	Same as above.
"Unexpected response to R-cmd; giving up."	Same as above.
"Unexpected response to E-cmd; giving up."	Same as above.
"Unexpected response to F-cmd; giving up."	Same as above.
"Unexpected response to A-cmd; giving up."	Same as above.
MWR.CFG "Cannot open MWR.CFG file."	The MWR.CFG file does not exist.
"RADIOMETER IDENTIFICATION line missing.	Edit MWR.CFG to correct the problem.
"COMPUTER CONFIGURATION line missing."	Same as above.
"CALIBRATION line missing."	Same as above.
"TIP CONFIGURATION line missing."	Same as above.
"LOS CONFIGURATION line missing."	Same as above.
"RETRIEVAL COEFFICIENTS line missing."	Same as above.
"WARM-UP CONFIGURATION line missing."	Same as above.
"PLOT CONFIGURATION line missing."	Same as above.
"IRT CONFIGURATION line missing."	Same as above.

4.2 List and description of files

The files installed by the user and created by MWR.EXE are listed in the following table by directory along with an explanation of their purpose. Files that are subject to user modification are marked with an asterisk.

File	Purpose
C:\MWR	
MWR.EXE	The executable MWR program.
MWR.CFG*	The configuration file for the MWR program. It must exist for the program to run.
MODE*	This file dictates the operating mode of the radiometer. It contains either LOS, TIP, DIAG, or EXIT. If this file does not exist the MWR program will create it with an entry of TIP.
ND_CALIB.LOG	This file contains up to 3000 most recent tip curve results. The file is created by MWR.EXE when valid tip curves are acquired.
OFFSET.LOG	This file is created by MWR.EXE. If contains the number of elevation stepper motor steps determined by the pointing correction to be needed to offset pointing errors.
NN_YYYYMMDD_HHMMSS.TMP	The currently open data file. It is created by MWR.EXE. NN is the serial number, YYYY is the 4-digit year, MM is the month, DD is the day of the month, HH is the hour, MM is the minute, and SS is the second that the file was created. Example: 33_20020715_230000.TMP was created at 23:00:00 on 15 July 2002 by radiometer 33. At the end of a user-specified interval this file is copied to C:\SEND_DIR and the .TMP extension changed to . DAT.
NN_YYYYMMDD_HHMMSS.ERR	If a fatal error occurs, this file is created. The file contains the date, time and description of the fatal error. It is copied to C:\SEND_DIR.
C:\SEND_DIR	
NN_YYYYMMDD_HHMMSS.DAT	A completed data file. YYYY is the 4-digit year, MM is the month, DD is the day of the month, HH is the hour, MM is the minute, and SS is the second that the file was created. Example: 33_20020715_230000.TMP was created at 23:00:00 on 15 July 2002 by radiometer 33.
NN_YYYYMMDD_HHMMSS.ERR	If a fatal error occurs, this file is created. The file contains the date, time and description of the fatal error.

4.3 Format of the data output file

When the MWR.EXE program is first started, and at specified intervals thereafter, it will create a new data file in the C:\MWR directory using the naming convention nn_yyyymmdd_hhmmss.TMP where nn is the radiometer serial number, yyyy is the 4-digit year, mm is the month, dd is the day of the month, hh is the hour, mm is the minute, and ss is the minute at the time the file was created. After the interval specified in the MWR.CFG file, the current data file is closed; this file (and any other .TMP file in C:\MWR) is then copied to the data directory C:\SEND_DIR; the extension is changed from .TMP to .DAT. The .TMP files in C:\MWR are then deleted.

The format of the data in each data file is as follows:

```
There are 4 different types of records (lines) possible in a data file.
The first element of each line is an integer indicating the line type:

0 = header line
1 = blackbody data line
2 = LOS data line
3 = TIP summary line
4 = TIP data line

========
 HEADER  (line type = 0)
========

There are currently six lines in the header.

Line 1 - hardware/software identification
_________________________________________

type, line, mwr_serial_number, software_version,
            last_software_revision_date (year, month, day)


Line 2 - calibration and general parameters
___________________________________________

type, line, last_calibration_date (yy mm dd),
            noise_injection_temperature_at_nominal_temperature_23.8,
            noise_injection_temperature_at_nominal_temperature_31.4,
            nominal_noise_diode_temperature,
            temperature_correction_coef_23.8, temperature_correction_coef_31.4,
            window_correction_coef_23.8, window_correction_coef_31.4,
            autocalibration_enabled, max_calibration_age, min_new_tips,
            min_valid_tips, calibration_check_factor


Line 3 - TIP setup
__________________

type, line, sample_time_sky, sample_time_blackbody,
```

```
            sample_time_blackbody+noise_diode,gunn_diode_warmup_time,
            number_of_elevation_angles, elev_angle_1, ... , elev_angle_N,
            azimuth_angle, minimum_correlation_coef, max_tip_change[%]


Line 4 - LOS setup
__________________

type, line, sample_time_sky, sample_time_blackbody,
            sample_time_blackbody+noise_diode,gunn_diode_warmup_time,
            number_of_sky_samples_per_blackbody_sample, elevation_angle,
            azimuth_angle


Line 5 - retrieval parameters
_____________________________

type, line, vapor_retrieval_coefficient_0, vapor_retrieval_coefficient_1,
            vapor_retrieval_coefficient_2, vapor_retrieval_rms_accuracy,
            liquid_retrieval_coefficient_0, liquid_retrieval_coefficient_1,
            liquid_retrieval_coefficient_2, liquid_retrieval_rms_accuracy,
            mean_atmos_radiating_temp_23.8, mean_atmos_radiating_temp_31.4,
            cosmic_background_temperature


Line 6 - IRT setup
__________________

type, line, irt_serial_number, slope[K/V], offset[K]


================
 BLACKBODY DATA  (line type = 1)
================

type, date (year, month, day), time (hour, minute, second, 1/100ths),
            number_of_LOS_data_lines, wet_window, tknd, tkxc, tkbb, tkair,
            tnd23, tnd31, bb23, bb31, bbn23, bbn31

where: wet_window = 1 (moisture detector ON) or 0 (detector OFF)
       tknd  = noise diode mount temperature (K)
       tkxc  = mixer temperature (K)
       tkbb  = blackbody temperature (K) (average of 2 sensors)
       tkair = ambient temperature (K) (only on units 20 and 21)
       tnd23 = noise injection temperature (at 23.8 GHz) adjusted to tkbb
       tnd31 = noise injection temperature (at 31.4 GHz) adjusted to tkbb
       bb23  = signal (counts) at 23.8 GHz viewing blackbody (noise diode OFF)
       bb31  = signal (counts) at 31.4 GHz viewing blackbody (noise diode OFF)
       bbn23 = signal (counts) at 23.8 GHz viewing blackbody (noise diode ON)
       bbn31 = signal (counts) at 31.4 GHz viewing blackbody (noise diode ON)
```

```
==========
 LOS DATA  (line type = 2)
==========

type, line, date (year, month, day), time (hour, minute, second, 1/100ths),
            vapor, liquid, tbsky23, tbsky31, ir_temp, sky23, sky31

where: vapor   = integrated water vapor along line-of-sight (LOS) path (cm)
       liquid  = integrated liquid water along line-of-sight (LOS) path (cm)
       tbsky23 = sky brightness temperature at 23.8 GHz (K)
       tbsky31 = sky brightness temperature at 31.4 GHz (K)
       ir_temp = temperature reported by IR thermometer (K)
       sky23   = signal (counts) at 23.8 GHz viewing sky
       sky31   = signal (counts) at 31.4 GHz viewing sky

NOTE:  1. The number of LOS data lines is given by the BLACKBODY parameter
          "number_of_LOS_data_lines".  (Maximum = 1024)

       2. The date/time of the first LOS DATA line matches that of the prior
          BLACKBODY entry.

=============
 TIP RESULTS  (line type = 3)
=============

type, date (year, month, day), time (hour, minute, second, 1/100ths),
            number_of_TIP_data_lines, tnd23i, tnd31i, r23, r31,
            vapor, liquid, tbsky23, tbsky31

where: tnd23i = noise injection temperature at 23.8 GHz derived from this tip (K)
       tnd31i = noise injection temperature at 31.4 GHz derived from this tip (K)
       r23    = correlation coefficient for 23.8 GHz regression
       r31    = correlation coefficient for 31.4 GHz regression
NEW    vapor   = integrated water vapor derived from tip curve (cm)
NEW    liquid  = integrated liquid water derived from tip curve (cm)
NEW    tbsky23 = sky brightness temperature at 23.8 GHz derived from tip (K)
NEW    tbsky31 = sky brightness temperature at 31.4 GHz derived from tip (K)

==========
 TIP DATA  (line type = 4)
==========

type, line, sky23, sky31

where: sky23   = signal (counts) at 23.8 GHz viewing sky
       sky31   = signal (counts) at 31.4 GHz viewing sky

NOTE:  1. The number of TIP data lines is given by the TIP RESULTS parameter
          "number_of_TIP_data_lines".  (Maximum = 20)  These are in the same
          order as the elevation angles specified in HEADER line 3.

       2. The date/time of the TIP RESULTS line matches that of the prior
          BLACKBODY entry and the first entry in the prior LOS DATA group.
```

4.4 Format of the ND_calib.log file

The ND_CALIB.LOG file contains the results of the 3000 most recent tip curves. Once 3000 entries have been made in the file, the next entry overwrites the first entry, and so forth. If auto-calibration is enabled, the current calibration and its date are also stored in this file. The format of the file is as follows:

```
line 1: first last next total

where:  first = the line number of the first tip in the current calibration

        last = the line number of the last tip in the current calibration

        next = the line number where the next tip result will be stored

        total = the total number of tip entries in the file

lines 2-3001: date time tkbb tkmx tknd tnd23i tnd23nom tcoef23 abdev23 tnd31i
              tnd31nom tcoef31 abdev31

where:  date = year month day (yymmdd)
        time = hour minute second (hhmmss)
        tkbb = the temperature of the blackbody reference target (K)
        tkmx = the temperature of the mixer (K)
        tknd = the temperature of the noise diode (K)
        tnd23i = the 23.8 GHz noise injection temperature from this tip curve
        tnd23nom = the 23.8 GHz noise injection temperature at 290 K
                   (the intercept of the regression of tnd23i vs tkbb-290)
        tcoef23 = the 23.8 GHz temperature coefficient
                  (the slope of the regression of tnd23i vs tkbb-290)
        abdev23 = the mean absolute deviation about the regression of tnd23i
                  vs tkbb-290
        tnd31i = the 31.4 GHz noise injection temperature from this tip curve
        tnd31nom = the 31.4 GHz noise injection temperature at 290 K
                   (the intercept of the regression of tnd31i vs tkbb-290)
        tcoef31 = the 31.4 GHz temperature coefficient
                  (the slope of the regression of tnd31i vs tkbb-290)
        abdev31 = the mean absolute deviation about the regression of tnd31i
                  vs tkbb-290
```

4.5 Format of MWR.CFG file

Each parameter in the MWR.CFG file, its type, and its meaning are described in the following table.

RADIOMETER IDENTIFICATION		
serial_number	integer	The serial radiometer serial number. This number will be used to generate a unique 3-digit extension for the data files. A value of "000" will cause to software to simulate a radiometer.
COMPUTER CONFIGURATION		
comm_port	integer	The serial communications port on the computer to be used to connect with the radiometer. Usually set to 1.
baud_rate	integer	1200 or 9600 baud. If this line is missing, 9600 is assumed.
data_directory	text string	The name of the directory where completed data files are to be placed. *Must be enclosed in single quotes*, e.g. 'C:\SEND_DIR'.
new_file_interval	integer	The interval in minutes at which the old data file is closed and a new file opened. Usually set to 60 minutes.
display	integer	If set to 1, then the graphical display is enabled; otherwise, the textual display is enabled.
CALIBRATION		
calibration_date	(yy mm dd)	The date of the most recent calibration update entered as 3 space-delimited 2-digit integers; e.g., 20 December 1997 would be represented as 97 12 20. If automatic calibration updates are enabled, the date of the latest calibration recorded in the file ND_CALIB.LOG is used instead of this date.
auto_calibration	integer	If set to 1, then automatic calibration is enabled; otherwise it is disabled.
max_calibration_age	integer	If automatic calibration is enabled, this specifies the interval in days at which the calibration is checked and updated if needed. Note that if the mode is set to TIP, then the calibration will be updated continuously.
min_new_tips	integer	The minimum number of new tips used to derive a median value of noise injection temperature to be compared with the current calibration.
min_valid_tips	integer	The minimum number of valid tips used in the robust regression of noise injection temperature vs. reference temperature.
tolerance_factor	float	This factor times the mean absolute deviation in the current calibration determines how far the median of the new values can be from the current calibration before the current calibration is judged to need updating.
tnd23nom	float	The default 23.8 GHz noise injection temperature at T_nominal. If auto-calibration is disabled, this is the radiometer calibration.
tnd31nom	float	The default 31.4 GHz noise injection temperature.

t_nominal	float	The temperature to which the noise injection temperature is referenced. Usually 290 K.
tcoef23	float	The temperature correction coefficient used to adjust tnd23nom to the actual blackbody reference temperature.
tcoef31	float	The 31.4 GHz temperature correction coefficient.
win23	float	The correction coefficient used to correct the 23.8 GHz brightness temperature for the contribution of the foam window.
win31	float	The 31.4 GHz window correction coefficient.

TIP CONFIGURATION

sky_dwell	integer	The time in milliseconds to sample the sky for each angle in the tip curve.
blackbody_dwell	integer	The time in milliseconds to sample the blackbody target with the noise diode off.
noise_dwell	integer	The time in milliseconds to sample the blackbody target with the noise diode on.
number_elev_angles	integer	The number of elevation angles in a tip curve.
elev(1)	float	The first elevation angle (degrees) in the tip curve.
...		
elev(n)	float	The last elevation angle in the tip curve.
azimuth	float	The azimuth angle for the tip curve. Usually set to 0.
min_R	float	The minimum correlation coefficient of the tip regression for a valid (cloud-free) tip curve.
max_iter_change	float	The maximum change (%) for tip iteration convergence.

LOS CONFIGURATION

sky_dwell	integer	The time in milliseconds to sample the sky.
blackbody_dwell	integer	The time in milliseconds to sample the blackbody target with the noise diode off.
noise_dwell	integer	The time in milliseconds to sample the blackbody target with the noise diode on.
n_sky_per_bb	integer	The number of sky samples per blackbody sample. If set to 1, then the "observing cycle" will match the previous version of the software. A value >1 will permit acquisition of consecutive sky samples at about 2.67-second intervals. Maximum value = 1024.
elev	float	The elevation angle (degrees) to sample. Usually set to 90.
azimuth	float	The azimuth angle to sample. Usually set to 0.

RETRIEVAL COEFFICIENTS

v0, v1, v2, vrms, Tmr23	float	The statistical retrieval coefficients for water vapor, the RMS uncertainty in the retrieval, and the mean atmospheric radiating temperature at 23.8 GHz for each month.
l0, l1, l2, lrms, Tmr31	float	The statistical retrieval coefficients for liquid water, the RMS uncertainty in the retrieval, and the mean atmospheric radiating temperature at 31.4 GHz for each month.
T_cosmic	float	The cosmic background radiating temperature; = 2.75 K.

WARM-UP CONFIGURATION

min_T_diff	float	the minimum acceptable difference (K) between the noise diode temperature and the blackbody temperature for thermal stabilization. Usually set to 20.
max_dTdt	float	Maximum rate of change of mixer and noise diode temperatures (K/minute) for thermal stabilization. Usually set to 0.5.
max_warmup_time	integer	Maximum allowable mixer and noise diode warm-up time (minutes). Usually set to 60.
LO_delay	integer	Local Oscillator warm-up delay (milliseconds). The sets the delay interval after a LO is powered before a measurement is made.
moisture_threshold	float	The signal level (volts) above which the moisture sensor indicates ON and the wet_window flag is set. Usually set to 1.0 volts.

PLOT CONFIGURATION

minimum_time	float	Not used in version 4.12 (auto-scaled instead).
maximum_time	float	Usually set to current time (i.e. 0).
time_increment	float	Tic marks in minutes.
minimum_temp	float	Minimum temperature to plot (K). The value selected here depends on location. In the Artic this value might be 253, whereas in the tropics it might be 293.
maximum_temp	float	Maximum temperature to plot (K). Usually above the set point for noise diode thermal stabilization; near 333 K.
temp_increment	float	Tic marks in K.
minimum_vapor	float	Minimum water vapor amount to plot (cm). Usually = 0.
maximum_vapor	float	Maximum water vapor amount to plot. Varies by location.
vapor_increment	float	Tic marks in cm.
min_airmass	float	Minimum airmass value to plot. Usually set to 0.
max_airmass	float	Maximum airmass value to plot. Usually set to 3.5.
airmass_increment	float	Airmass tic marks.
minimum_opacity	float	Minimum opacity to plot. Usually set to 0.
maximum_opacity	float	Maximum opacity to plot. Depends on water vapor amount or location.
opacity_increment	float	Opacity tic marks.

IRT CONFIGURATION

irt_serial_number	integer	IRT serial number; 0 indicates no IRT is installed.
irt_channel_number	integer	MWR A/D channel to which the IRT is connected.
irt_slope	float	Slope of voltage-to-Kelvin conversion.
irt_offset	float	Offset of voltage-to-Kelvin conversion.

4.6 Sample MWR.CFG file

```
ARM Microwave Radiometer Configuration File

RADIOMETER IDENTIFICATION (Line 1 in data file)
001            Serial number (3 digits; 000=simulated instrument)

COMPUTER CONFIGURATION
1              COMM port of computer
9600           Baud rate (if this line is missing 9600 is assumed)
'C:\SEND_DIR'  Directory where data files are placed for collection
60             Create a new data file every N minutes
1              1 = graphical display, 0 = textual display

CALIBRATION (Line 2 in data file)
02 08 13       Date of latest calibration update
1              automatic calibration switch (1=enabled, 0=disabled)
1              maximum number of days between calibration checks
50             minimum number of new tips needed to check calibration
500            minimum number of tips needed for regression of Tnd on Tbb
3.0            factor for calibration change test limits
234.56         23.8 GHz noise injection temperature @ T_nominal
345.67         31.4 GHz noise injection temperature @ T_nominal
290.0          T_nominal (K)
+0.06          23.8 GHz temperature correction coefficient (K/K)
-0.02          31.4 GHz temperature correction coefficient (K/K)
0.00164        23.8 GHz window correction coefficient
0.00217        31.4 GHz window correction coefficient

TIP CONFIGURATION (Line 3 in data file)
1000           sky sampling time (milliseconds)
1000           blackbody sampling time (milliseconds)
1000           blackbody+noise diode sampling time (milliseconds)
10             number of elevation angles
 19.5          first elevation angle in TIP
 23.6
 30.0
 41.8
 90.0
138.2
150.0
156.4
160.5
 90.0          last elevation angle in TIP
0.             azimuth angle
0.998          minimum correlation coefficient for a valid tip
0.1            max allowable change in TIP iteration convergence (%)

LOS CONFIGURATION (Line 4 in data file)
1000         sky sampling time (milliseconds)
1000         blackbody sampling time (milliseconds)
1000         blackbody+noise diode sampling time (milliseconds)
```

```
1            number of sky samples per blackbody sample
90.0           elevation angle
0.00           azimuth angle

RETRIEVAL COEFFICIENTS for January thru December (Line 5 in data file)
       vap0          vap1         vap2        rmsvap      Tmr23
    .23012E-01   .21866E+02  -.12624E+02  .57662E-01   269.348
    .30417E-01   .21894E+02  -.12620E+02  .60594E-01   270.895
    .31403E-01   .22062E+02  -.12657E+02  .60905E-01   273.895
    .51116E-01   .22070E+02  -.12531E+02  .90348E-01   278.636
    .51971E-01   .22455E+02  -.12829E+02  .92660E-01   282.634
    .72164E-01   .22449E+02  -.12717E+02  .99163E-01   285.446
    .59213E-01   .22704E+02  -.13001E+02  .80860E-01   286.779
    .79709E-01   .22527E+02  -.12879E+02  .99144E-01   286.327
    .70301E-01   .22324E+02  -.12690E+02  .92464E-01   283.734
    .51505E-01   .22260E+02  -.12693E+02  .82078E-01   281.058
    .22715E-01   .22224E+02  -.12732E+02  .60145E-01   275.067
    .19107E-01   .22068E+02  -.12714E+02  .57881E-01   271.265
       liq0         liq1         liq2        rmsliq      Tmr31
   -.12628E-01  -.18700E+00   .62164E+00  .27109E-02   265.679
   -.13400E-01  -.19731E+00   .65347E+00  .31093E-02   267.229
   -.13566E-01  -.21847E+00   .69196E+00  .34929E-02   270.302
   -.12692E-01  -.25683E+00   .75306E+00  .32401E-02   275.247
   -.11785E-01  -.27566E+00   .78367E+00  .35229E-02   279.721
   -.11960E-01  -.27868E+00   .79723E+00  .35628E-02   283.021
   -.11244E-01  -.28197E+00   .80127E+00  .36922E-02   284.706
   -.11624E-01  -.28431E+00   .81029E+00  .36575E-02   284.266
   -.12390E-01  -.27439E+00   .79368E+00  .38709E-02   281.314
   -.12432E-01  -.27164E+00   .78544E+00  .35918E-02   278.299
   -.13643E-01  -.22692E+00   .71156E+00  .35936E-02   271.644
   -.13284E-01  -.19346E+00   .64898E+00  .30835E-02   267.580
2.75           Cosmic Background Temperature (K)

WARM-UP CONFIGURATION
10.0         Minimum difference between noise diode and blackbody (K)
0.50         Maximum dT/dt of mixer/noise diode temperature (K/min)
720          Maximum allowable warm-up time (minutes)
100          Local Oscillator warm-up delay (milliseconds)
0.1          Moisture sensor ON/OFF threshold (volts)

PLOT CONFIGURATION
-20.         Minimum time to plot (minutes)
0.           Maximum time to plot (minutes)
5.           Time increment (minutes)
293.         Minimum temperature to plot (K)
333.         Maximum temperature to plot (K)
10.          Temperature increment (K)
0.           Minimum PWV to plot (cm)
2.           Maximum PWV to plot (cm)
0.5          PWV increment (cm)
0.           Minimum airmass to plot
3.5          Maximum airmass to plot
0.5          Airmass increment
0.0          Minimum opacity to plot
```

```
0.4          Maximum opacity to plot
0.1          Opacity increment

IRT CONFIGURATION (Line 6 in data file)
0000           IRT serial number (0000 = no IRT)
13             IRT attached to radiometer A/D channel no.
1.0            IRT voltage conversion slope (K/volt)
223.15         IRT voltage conversion offset (K)
```

4.7 Description of operating modes (INIT, LOS, TIP, DIAG)

4.7.1 INIT mode

When the MWR.EXE program is first started, the mode is set to INIT to initialize the software and hardware. In this mode the graphical display is initialized if enabled, the serial port is initialized and checked, and the radiometer is checked for thermal stabilization. That is, the temperatures of the mixer and noise diode must be increasing by less than the rate specified in MWR.CFG and they must be greater than the blackbody temperature by the amount specified in MWR.CFG. The program will loop until thermal stabilization is attained or until the maximum allotted time (specified in MWR.CFG) is exhausted. If the graphical display is disabled, the warm-up can be aborted by typing Ctrl-c at the keyboard.

4.7.2 LOS mode

In Line-of-Sight (LOS) mode, the radiometer field of view is pointed along a direction determined by the azimuth and elevation angles specified in MWR.CFG. In this mode, measurements of the sky along the line-of-sight are made in addition to measurements of the internal blackbody reference target with and without the noise diode energized. The latter are necessary to apply the calibration and convert the signal voltages to brightness temperatures. Multiple sky measurements may be made for each measurement of the blackbody in order to attain a higher sky sampling rate. The number of sky samples per blackbody sample is specified in the MWR.CFG file.

4.7.3 TIP mode

In TIP mode, the field of view of the radiometer is scanned across the sky by changing the elevation angle for a fixed azimuth. Under clear sky conditions these scans or tip curves may be used to calibrate the noise diode (i.e. to determine its noise injection temperature, the amount the measured microwave brightness temperatures must increase when it is energized). It is similar to LOS mode in that multiple sky measurements are made for each measurement of the blackbody reference target but, unlike LOS mode, the sky measurements are along different lines-of-sight. The zenith (straight up) measurements made as part of the TIP mode are identical to LOS measurements and are reported as LOS measurements. In this way LOS data are not interrupted during TIP mode operation.

4.7.4 DIAG mode

In diagnostic mode, the elevation mirror is pointed at the blackbody reference target and measurements of the signal voltages with the noise diode off and on are made repeatedly to help diagnose communications and radiometer hardware problems. The graphical display should be disabled in diagnostic mode so that more extensive text output is visible. Diagnostic mode may be exited by typing Ctrl-c.

4.8 Automatic self-calibration

The program is capable of automatically checking and updating the radiometer calibration. The results of the most recent 3000 valid tip curves (and calibration updates, if auto-calibration is enabled) are stored in the file C:\MWR\ND_CALIB.LOG. The program will create this file if it does not initially exist.

4.8.1 Startup calibration

If auto-calibration is enabled the radiometer will be placed in TIP mode when the program is (re)started regardless of the entry in the MODE file. This is done to check the calibration whenever the radiometer power has been cycled since this is typically when calibration changes occur.

Once a sufficient number of new tip curves have been acquired, the median of their calibration values (the noise injection temperature) is compared with the current calibration. Specifically, if the difference between the current calibration and the median of the new tip values is greater than a user-specified factor times the uncertainty in the current calibration (computed as the mean absolute deviation about the regression from which the current calibration was derived), then a new calibration is judged to be needed.

If a new calibration is warranted, additional tip curves are acquired until a number sufficient to perform a new regression to update the calibration are obtained. Until the new regression is carried out, the median of the new tip curve-derived noise injection temperatures is used as an interim calibration. Once the calibration is updated, the operating mode will return to that specified in the MODE file after the MODE file is next read.

4.8.2 Clear sky calibration

If auto-calibration is enabled the radiometer will be placed in TIP mode whenever the sky is clear. The sky is judged to be clear when the standard deviation of the last 100 samples of liquid water path falls below a preset value (adjustable by the user; 0.008 mm recommended) that is near the detection threshold or noise floor of the instrument. The calibration will be updated after each valid tip curve is acquired. The radiometer will remain in TIP mode until the end of the current data collection period (typically an hour). At the beginning of each (hourly) collection period the mode will be reset according to the contents of the MODE file. Thus if the MODE is set to LOS, but the standard deviation of the liquid water path is less than the clear sky value, the MODE will be set to TIP. *To prevent automatic clear sky calibration updates, simply set the clear sky LWP standard deviation threshold to zero.*

4.8.3 Periodic calibration

If the operating mode is set to LOS and the time since the last calibration is greater than the maximum allowable number of days, then the mode is set to TIP to permit the calibration to be checked and updated, if necessary. (If the mode is set to TIP, then the calibration is continually updated as valid tip curves are acquired. The disadvantage to continuous tip curves is a lower zenith sampling rate.)

4.9 Automatic leveling/alignment of the elevation mirror

Over time the elevation mirror may slip slightly on the shaft of the stepper motor. This will cause an offset in the pointing angle of the mirror. Although this will have a negligible effect on zenith observations, it will cause tip curves to appear cloudy (because the data points will not be co-linear and thus the correlation coefficient R will be reduced). This can substantially reduce the number of valid tip curves acquired. To overcome this, the MWR.EXE software will automatically align or "level" the elevation mirror if automatic calibration is enabled.

For each tip curve in the 31.4 GHz channel the angular offset required to move each data point onto the regression line is computed for elevation angles less than 31° (airmasses ≥ 2). The median of these offsets is computed and added to an array of the most recent 1000 offsets. The median of this array is updated each hour and the result used to compute the correction, which is converted to the integer number of motor steps necessary to adjust for the offset. This value is stored in the file `offset.log`. (Each motor step is 0.45°. Typical offset corrections are 1 or 2 steps.)

The 31.4 GHz channel is used because it is much less sensitive to water vapor than the 23.8 GHz channel, and thus is less susceptible to errors from spatial gradients in water vapor across the range of tip angles.