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Gridded Meteorological Messages (METGMs) with User-Selected Parameters from GRIB2 Formatted Model Output Files

by J Cogan

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14. ABSTRACT
Several NATO nations use the gridded meteorological (MET) message (METGM) for MET support to artillery and for other applications. Software available at NATO can produce a METGM from certain numerical weather prediction output, but at present only for European and derivative models such as the Unified Model (UM) from the UK and the US Air Force's Global Air Land Weather Exploitation Model (GALWEM), which is a variant of the UM. This report briefly describes a software package that converts Global Forecast System data into a METGM that also may be used for GALWEM output files. Text files produced as part of the process are potentially useful for model evaluation. The software is a research and evaluation tool, and is not recommended for application in an operational system.

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1. Introduction

Several NATO nations use the gridded meteorological (MET) message (METGM) for MET support to artillery and for other applications. The METGM essentially is a 3-D output file, or 4-D if it has more than one forecast time, from a numerical weather prediction (NWP) model in a standard NATO format (STANAG 6022 2010). Software available at NATO is able to convert certain NWP output into a METGM, but at present only for European and derivative models such as the Unified Model (UM) from the UK and the US Air Force's Global Air Land Weather Exploitation Model (GALWEM), which is a variant of the UM. However, conversion software currently is not readily available for other NWP models such as the Global Forecast System (GFS) used by the US National Weather Service.

This technical note briefly describes a software package that converts GFS output into a METGM that also may be used for GALWEM output files. The text files generated as part of the conversion process may be used for model evaluation. While the software can convert a NWP model output file into a METGM, it is a research and evaluation tool, and is not recommended for application in an operational system.

2. Software Description

The software consists of a combination of modified Python 3 and Bash scripts along with the commonly available wgrib2 set of programs from the National Oceanic and Atmospheric Administration (NOAA), and a modified version of a FORTRAN program originally written by Weber (2002a) for use in a NATO artillery test. The scripts are based on those developed earlier by Cogan (2019a) for generating METGMs from Weather Research and Forecasting (WRF) model output, and the FORTRAN program is essentially the same as briefly described in the same reference. The Bash script receives user input and directs the operation of the called wgrib2 programs, Python scripts, and the FORTRAN program. Figure 1 outlines the processes in the Bash script, *gfs2metgm.sh*, in the form of a flowchart that shows the queries to the user and the calls to the included Python scripts and FORTRAN program.

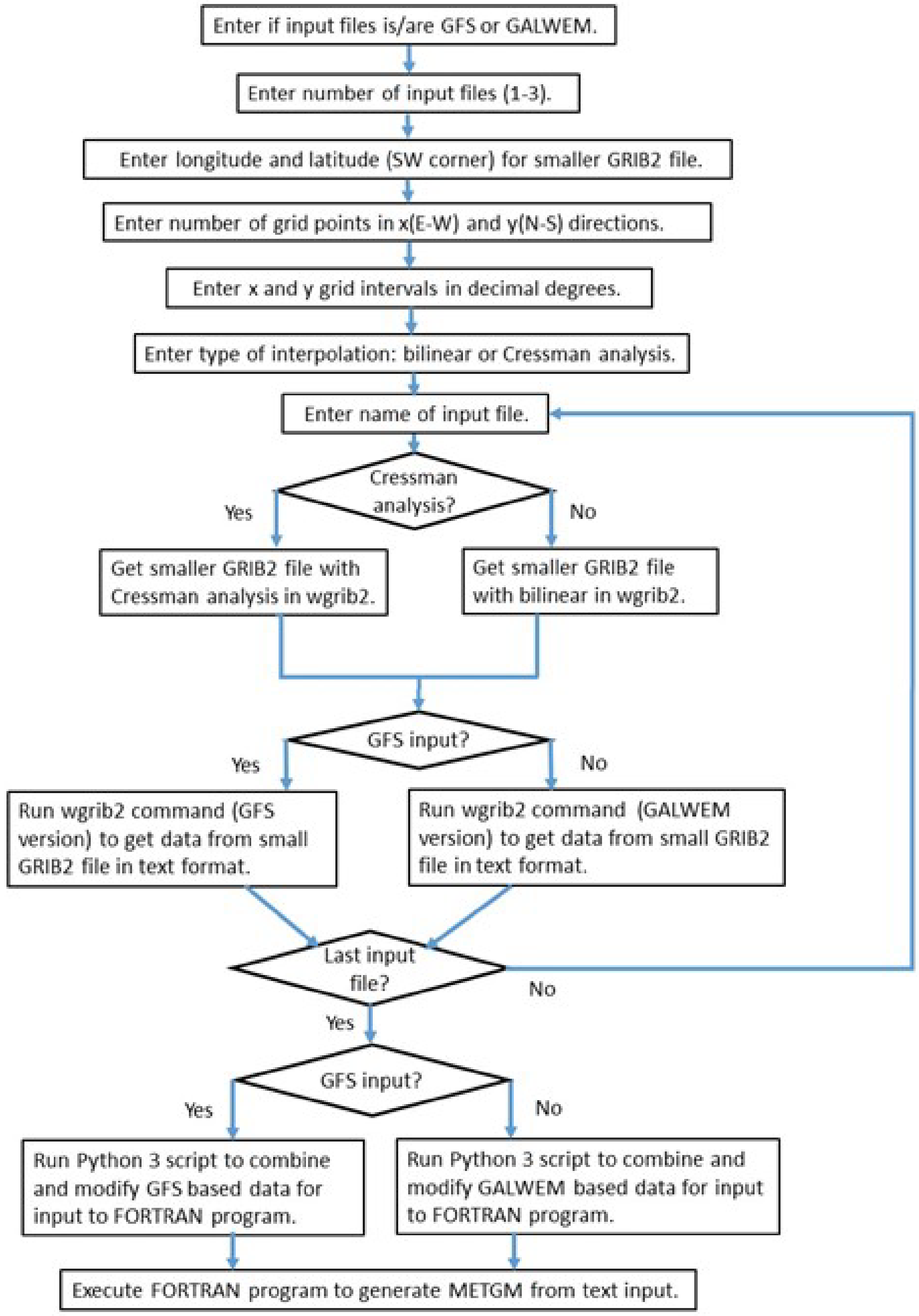

Fig. 1 Flowchart of *gg2metgm.sh* showing the user queries, main components, and various decision points

The Bash script *gg2metgm.sh* controls the flow of the software and queries the user for several parameters used in the called scripts and programs, as illustrated in Fig. 1. The first query asks if the input file is GFS output; if not, then it is assumed to be GALWEM output. The next query requests the number of input files (up to three) to be processed into a METGM. The files may be output from either GFS or GALWEM, but not a mixture of both. The script then queries the user for the longitude and latitude in decimal degrees of the lower left (southwest) corner of the user-defined domain for the smaller GRIB2 file that is extracted from the initial input GFS or GALWEM file. The METGM is constructed with part or all of this smaller file using the procedure mentioned at the end of this section with respect to the FORTRAN program. For west longitude, the user may enter longitude either as a negative number (e.g., –77.21 vs. 77.21 W) or as a number equal to 360 minus west longitude, which is always positive (e.g., 282.79 vs. 77.21 W). South latitude is entered as a negative number (e.g., –35.5 for 35.5 S). Afterward, the user is asked to enter the number of x (east-west) grid points and y (north-south) grid points. The total horizontal x and y distances of the METGM should not exceed those of the smaller GRIB2 file. Then the user enters the grid interval in decimal degrees of longitude and latitude.

Wgrib2 interpolates data to the grid points of the smaller file when the horizontal grid intervals are smaller or larger than those of the input GFS file. The user chooses between two means to interpolate the data in the next query, using either Cressman analysis (https://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/cress_lola.html) or bilinear interpolation. The default is bilinear interpolation. Other available options include those noted on the wgrib2 webpage for interpolating to new grids (https://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/new_grid_interpolation.html). For GFS and GALWEM output, the horizontal grid interval currently is 0.25° for both longitude and latitude for standard operational output available from NOAA's National Centers for Environmental Prediction (NCEP) and the Air Force 557th Weather Wing (557th), respectively. However wgrib2 will process output with other intervals (e.g., 0.5° GFS). Cressman analysis takes considerably more time than bilinear interpolation and tends to produce output that may be overly smoothed. Based on trial runs, employment of bilinear interpolation led to incorrect results when the output file's domain covered less than 1° × 1° longitude and latitude (e.g., 5 × 5 grid points of the input file where the input file had a horizontal grid interval of 0.25°). The output derived from GFS data had unrealistic terrain elevations for some grid points (e.g., elevation value of over 5000 m for a region where the highest terrain is less than 1000 m) and other variables may have had odd values. Output from GALWEM data had only values for the bounding longitudes (e.g., for longitudes from –76.0° to –76.6° with a requested interval of 0.1° the output included only values at –76.0° and –76.6°), although the latitudes had the requested interval. After communication with the developers of wgrib2, the issue was corrected with a temporary fix while awaiting a more complete resolution. The "bug" is briefly described at the top of the following webpage: https://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/new_grid.html. As such, interpolation based on either method, if the temporary fix is installed, will now produce output for all requested longitudes and latitudes for domains covering distances less than 1° × 1° of longitude and latitude.

After choosing the interpolation method, the script begins a loop that is executed one to three times depending on the number of input files. Within the loop, the script queries the user for the name of the first input file. The name must include the path, either the full path or relative to the directory that contains *gfs2metgm.sh*. The script then executes one of two wgrib2 commands to extract a smaller GRIB2 file from the input file depending on the chosen interpolation method. Then another wgrib2 command is executed depending on whether the input file was from GFS or GALWEM. This second command converts the smaller GRIB2 file into a text format. Each iteration of the loop produces one file in text format. At this point, the script checks the number of input files read in and, if the last one has been processed, the loop ends. Otherwise, the user is queried for the next input filename and so on until the last of up to three files are processed. After the loop ends, separate Python 3 scripts for GFS or GALWEM, *gfs2text.py* or *gal2text.py*, respectively, process the one to three text files generated via the loop. The Python scripts combine the separate text files if there are more than one and reformat the text for use by the FORTRAN program, *metascii2metgm_nt*, which in turn converts the text data into a METGM.

The FORTRAN program reads several parameters and the list of METGM heights from a parameter file, *gm_parameters*, modified as needed by the user before running *gfs2metgm.sh*. This file contains the first part of the output METGM name (date and time are appended to this initial part within the program), the number of x and y grid points for the METGM, the x and y grid intervals in decimal degrees, a time interval in seconds, and a list of the METGM heights (meters above ground level [AGL]) starting with the surface. The time interval does not affect the computations in the version of the FORTRAN program employed for the application described in this report, since there is no time interpolation between the input forecast times. However, it is a required input and is written to a description section in the output METGM. Cogan (2019a) presents a brief discussion on the use of *gm_parameters* as well as an example.

3. Executing the Software

The procedure for running the software is reasonably straightforward. The software requires that wgrib2 and Python 3.5 or higher be installed on the computer. A FORTRAN compiler able to work with FORTRAN 77 also is needed if compilation of the program *metascii2metgm_nt.f* is required. Additionally, a FORTRAN and a

C library routine are needed for compilation as noted in Cogan (2019a), specifically FORTRAN_LIB_METASCII2METGM and C_LIB_METASCII2METGM. The following subsections contain the procedures to execute the software starting with the “control” Bash script that calls the other scripts and programs.

3.1 Bash Script

The initial step is to type the name of the Bash script (./ required for most Linux systems):

./gfs2metgm.sh

An initial message is printed to the screen to remind the user to make sure the file *gm_parameters* has the correct values before continuing. The user then responds to the queries for the various parameters noted previously and in Fig. 1. In summary, the queries in order of appearance for input of one to three GFS files are listed in Table 1.

Table 1 List of queries to the user from *gg2metgm.sh* in the order of appearance. The response column has the potential responses or the type of response (e.g., name of file).

Query	Response
Is (Are) input file(s) from GFS or from GALWEM?	GFS (y) or GALWEM (other character)
Number of input files?	1 to 3
Longitude and latitude of SW (lower left) corner of smaller domain?	Decimal degrees. Negative for west or south. For west longitude can use 360-longitude vs. negative.
Number of x (east-west) and y (north-south) grid points for smaller domain?	Each of 2 numbers must be 2 or more.
Intervals between the x and the y grid points?	2 numbers in decimal degrees
Type of interpolation to be employed?	Cressman analysis (c) or bilinear (b).
Name(s) of input file(s)? Repeated up to 3 times depending on number of files entered in first query.	Filename(s) including path if not in same directory.
Display screen output from FORTRAN program before ending script?	If yes enter y; any other character for no.

3.2 Wgrib2 Program Commands

Wgrib2 is a software package available from NOAA. A description of the software can be found at https://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/ and the many included links. The first command generates the smaller GRIB2 file for later processing. There are two options: using bilinear interpolation to grid points if not at the horizontal grid resolution of the input file or employing a method based on a Cressman analysis (see the URL in Section 2). The latter version (Cressman) appears to smooth the output GRIB2 file more than the bilinear interpolation method. The command line for bilinear interpolation is as follows:

wgrib2 INPUT_FILE -set_grib_type same -new_grid_winds earth -new_grid latlon LON:NX:IX LAT:NY:IY SMALL_GRIB2_FILE (1)

where INPUT_FILE is the input GFS or GALWEM output file; LON and LAT are the longitude and latitude in decimal degrees, respectively, of the lower left (approximately the SW) corner of the output grid; NX and NY are the number of x (N-S) and y (E-W) grid points of the output grid (must be 2 or more); IX and IY are the x and y grid intervals in decimal degrees; and SMALL_GRIB2_FILE is the output smaller GRIB2 file. West longitude may be written as negative degrees (e.g., 79° west as –79°) or as numbers greater than 180° up to 360° (i.e., 360 minus west longitude) where all values are taken as east longitudes (e.g., –77° expressed as 283°).

To use the method that employs a Cressman analysis, the command line is as follows:

wgrib2 INPUT_FILE –set_grib_type same –new_grid_winds earth –cress_lola LON:NX:IX LAT:NY:IY SMALL_GRIB2_FILE R1:….RN (2)

where R1:.... RN represent radii of coverage for the Cressman analysis. R values are in kilometers and the command line may have from 1 to N radii although 2 or 3 seem to work well (if only 1 radius is used then no colon (:) follows the number). The processing time is a function of how many radii are chosen so normally the user would select the fewest radii that can produce good output. The meaning of the other terms are the same as for the command line that uses bilinear interpolation (command line 1).

Following the generation of the small GRIB2 file, one of two wgrib2 commands produce the output data in text format depending on the source of the input files, GFS or GALWEM. The command line for GFS contains a number of variables that are eliminated by the relevant egrep (multiple grep) code (i.e., egrep –v). Data for 40, 15, and 0.4 hPa are removed since those levels do not have wind and relative humidity values. The fairly long wgrib2 command line for GFS is as follows:

wgrib2 SMALL_GRIB2_FILE -s | egrep "mb:|PRES:surface:|HGT:surface |:TMP:2 m above|:RH:2 m above|:UGRD:10 m above|:VGRD:10 m above|:PRMSL:"| egrep -v "5WAVH|CLMR|O3MR|ABSV|ICSEV|TCDC|GRLE|SNMR|RWMR|ICMR| 0.4 mb:|15 mb:|40 mb:" | wgrib2 -i SMALL_GRIB2_FILE -spread TEXT_OUT (3) where SMALL_GRIB_FILE is the output from either command line 1 or 2, TEXT_OUT is the output text file, UGRD is the u wind component (at 10 m AGL), VGRD is the v wind component (at 10 m AGL), and PRMSL is pressure at mean sea level. The other variables (after egrep and before egrep –v) have the usual meanings (e.g., HGT is height). The variables and data levels after egrip –v and before the pipe to the second call to wgrib2 are removed, as noted previously.

The command line for GALWEM contains fewer items than the one for GFS and the variable for the terrain height is MTERH:

wgrib2 SMALL_GRIB2_FILE -s | egrep "mb:|PRES:surface:|MTERH:|:TMP:2 m above|:RH:2 m above|:UGRD:10 m above|:VGRD:10 m above|:PRMSL:"
| wgrib2 -i SMALL_GRIB2_FILE -spread TEXT_OUT (4)

where MTERH is terrain height and the definition of the other names are the same as for GFS data.

3.3 Python 3 Scripts

Two Python 3 scripts, *gfs2text.py* and *gal2text.py* for GFS and GALWEM data, respectively, convert the text output from wgrib2 into the format needed for input to the FORTRAN program. Currently, up to three consecutive output files from either GFS or GALWEM may be processed by the respective script. These scripts also may be run independently of the main script using the appropriate TEXT_OUT file(s) from wgrib2 command line 3 or 4. For a text file derived from GFS output, use the following:

python3 gfs2text.py TEXT_OUTPUT INPUT_TEXT(s) (5)

where TEXT_OUTPUT is the text file for input to the FORTRAN program and INPUT_TEXT is/are the file(s) generated by wgrib2 command line 3. Currently, one to three input files may be entered on the command line. For a text file derived from GALWEM output, the command line is the same except for the script name:

python3 gal2text.py TEXT_OUTPUT INPUT_TEXT(s) (6)

where the meanings are the same as for command line 5. The output file from either command line 5 or 6 has to be copied to a file with the standard name used for the FORTRAN program input, that is, *grib2text.txt*. If the name for TEXT_OUTPUT is the same as the standard name, then this latter step is not required.

3.4 FORTRAN Program

The version of the FORTRAN program used to convert model data in text format into a METGM that is employed for the application of this report, *metascii2metgm_nt*, does not interpolate with respect to time. The suffix "_nt" indicates the version without time interpolation. The input times (also known as "time slices") are for the model forecast times only. An example could be GFS data for 0600 and 0900. Data are not computed for intermediate times such as for 0700 or 0800. Also, the program was modified so that the GFS or GALWEM values of surface pressure were used directly rather than computed using the mean sea level pressure and elevation. To run the program in a standalone mode (external to *gg2metgm.sh*), type the program name. The input file is *grib2text.txt*, as noted previously. In the Bash script, the output to screen is redirected into a file, and the user may want to do so as well when running the program independently. The program is run as follows:

```
./metascii2metgm_nt > screenoutput
```

where *screenoutput* is the name of the file that holds the screen output. If run separately, the input file must be named *grib2text.txt* and the user may choose a name other than *screenoutput* for the file to hold the output to screen (or simply display directly to the screen).

The output from *metascii2metgm* is a METGM in the older Edition 1 format. That format has been replaced by the newer Edition 2 format and plans are underway for further upgrades. Edition 2 is widely used and is likely to remain so for some years into the future. Fortunately, a NATO program is currently available to relevant users that among other features can convert an Edition 1 METGM into an Edition 2 version (and vice versa). This program has been used successfully to convert the METGM Edition 1 output from the program of this report into the equivalent Edition 2 METGM. The Edition 2 version was successfully tested using the most recent version of the trajectory simulation program GTRAJ, and the Edition 1 version had a successful outcome using a slightly older version of GTRAJ.

4. Data Samples

The text data produced by wgrib2 command line 3 has the format shown in Table 2. The information in the text file may be useful for comparisons of model output to observations or other configurations of the model. However, further processing may be required for a product that is more closely tailored to the application as was done here for the conversion to a METGM.

Table 2 Sections of output from wgrib2 command line 3 with a GFS output file as input for the 800-mb level and for the "surface" (e.g., 0, 2, and 10 m AGL) for pressure (PRES), temperature (TMP), and u component of wind (UGRD), respectively. Values are presented for TMP (K), UGRD (ms^{-1}), and PRES (Pa). Only a 2- × 2-grid point area was processed at the horizontal grid resolution of the GFS input (0.25°). Output from wgrib2 command line 4 for GALWEM data has the same format. Some variable names are different such as "MTERH" for terrain height vs. "HGT surface". Data also may be extracted for other grid sizes and for smaller or larger intervals (e.g., 11 × 11 grid points at an interval of 0.1°).

lon,lat,TMP 800 mb d=2019112600 6 hour fcst
282.000000,39.000000,278.191
282.250000,39.000000,277.891
282.000000,39.250000,277.791
282.250000,39.250000,277.491
lon,lat,UGRD 800 mb d=2019112600 6 hour fcst
282.000000,39.000000,8.0688
282.250000,39.000000,7.9388
282.000000,39.250000,8.2788
282.250000,39.250000,7.9988
lon,lat,PRES surface d=2019112600 6 hour fcst
282.000000,39.000000,98534.7
282.250000,39.000000,99272.3
282.000000,39.250000,98976.3
282.250000,39.250000,99232.3
lon,lat,TMP 2 m above ground d=2019112600 6 hour fcst
282.000000,39.000000,277.878
282.250000,39.000000,277.688
282.000000,39.250000,278.008
282.250000,39.250000,277.728
lon,lat,UGRD 10 m above ground d=2019112600 6 hour fcst
282.000000,39.000000,1.03509
282.250000,39.000000,0.87509
282.000000,39.250000,1.72509
282.250000,39.250000,0.91509

Text data in the format of Table 2 was not suitable for input to *metascii2metgm_nt* and consequently further processing was required using the respective Python 3 scripts.

Table 3 shows a sample of output from the Python 3 script for GFS data. It has several sections as follows. Part 1 has date and time information followed by a line with the number of x and y grid points, number of input files, and the number of parameters (always = 8). The next line has the forecast hour(s). The next set of lines have the longitude, latitude, and elevation (surface height) of the grid points. The line afterwards has the number of heights (surface excluded), number of the parameter, and type of vertical coordinate (2 = pressure). The column that follows contains the pressure levels starting with the lowest pressure level (highest pressure) above the surface up through the highest pressure level (lowest pressure). The next set of data has some of the heights for the listed pressure levels for the first grid point. The sample has two columns (two input files), but can have up to three columns, one for each input file. Part 2 starts with a line having the number of levels (includes the surface), the parameter number for temperature, and the type of vertical coordinate (pressure). A sample of the list of pressure levels follows, where 2001.00 represents the surface, which in turn is followed by two columns of temperatures for several of the pressure levels for the first grid point. For the samples of relative humidity and u component of wind values shown in the table, the column of pressure level values (same as for temperature) that appear in the output before each of those data sections are not repeated. The data are also for the first grid point. Part 3 has the information and data for surface pressure for the four grid points. There is only one level, the surface, as indicated by 2001.00. Although 7 is used as the identification parameter for both height and surface pressure, the location and placement in the line after "1" indicates that this section is for surface pressure.

Table 3 Output from the Python script (command line 5) with two GFS output files as input. The numbers for each part (numbers in bold italic within brackets) and the data name labels in the table are for clarity and are not in the output. Details may be found in the text immediately preceding this table.

```
     201912050000
        2   2   2   8
     3       6
      -78.0000  39.0000   228.060   Longitude, latitude, elevation
      -77.7500  39.0000   167.420
      -78.0000  39.2500   191.100
      -77.7500  39.2500   170.460
     30   7    2
        975.00
        950.00
        925.00
        900.00
        850.00
           .
           .
[1]       7.00
          5.00
          3.00
          2.00
          1.00
       237.830    244.718     Height above sea level
       447.450    453.002
       661.967    665.814
       881.117    883.336
      1333.760   1333.160
          .          .
          .          .
     33099.500  33090.600
     35315.300  35299.900
     38741.700  38715.100
     41556.200  41486.200
     46539.200  46447.300
```

Table 3 Output from the Python script (command line 5) with two GFS output files as input. The numbers for each part (numbers in bold italic within brackets) and the data name labels in the table are for clarity and are not in the output. Details may be found in the text immediately preceding this table (continued).

```
        31   5    2
          2001.00
           975.00
           950.00
           925.00
           900.00
           850.00
              .
              .
              .
          274.372    273.676     Temperature
          275.054    273.958
          274.755    272.766
          273.479    271.454
 [2]      271.791    270.056
          268.345    266.886

           84.300     85.500     Relative Humidity
           83.800     82.100
           82.700     81.400
           86.500     80.600
           93.100     79.800

            2.966      3.981     U wind component
            3.757      8.076
            8.672     12.214
           11.270     14.462
           13.066     16.093
```

```
        1    7    2
          2001.00
          976.310    977.424     Surface pressure
 [3]      983.366    984.576
          980.822    981.760
          983.206    984.080
```

The text output from the Python 3 script for either GFS or GALWEM data is input to the FORTRAN program (*metascii2metgm_nt*). Cogan (2019a) also contains information on another FORTRAN program, *readmetgm*, which is used to extract profiles of the several variables in text format for user-defined sections of the output grid. This program is a modified version of another one written by Weber (2002b). Use of *readmetgm* as described in Cogan (2019a) allows one to check how closely the METGM replicates the model output for the heights of the METGM at user-specified model grid points. Comparing the data at a common grid point helps minimize the need for horizontal interpolation.

Tables 4 and 5 present a small sample of the output from *metascii2metgm_nt* using *readmetgm* to express the data in text format for 1 grid point. A more complete sample of output from *readmetgm* may be found in Tables 8–11 of Cogan (2019a).

Table 4 Parts of the output from *metascii2metgm_nt* for 1 grid point showing [1] the selected METGM grid point, longitude, latitude, data level number (0 based), and elevation in the first and second lines; [2] heights AGL for the first 16 data levels; [3] parameter indicator and time slice (forecast) number (1 based); [4] grid point information as in the first line; [5] pressure (hPa) for the first 10 data levels; and [6] temperature (K) for the first 10 data levels. Note that the nominal precision of many of the listed values (5, 6, or more places to the right of the decimal point) is copied from the METGM file and does not represent actual precision or accuracy. Data section numbers and labels in the table are for clarity and do not appear in the output.

[1]	`Grid point (x,y,lon,lat):   3   3   -78.00000  39.00000` `                 0     228.000000`

[2]	`  0  height =       0.00`
	`  1  height =     100.00`
	`  2  height =     250.00`
	`  3  height =     500.00`
	`  4  height =     750.00`
	`  5  height =    1000.00`
	`  6  height =    1500.00`
	`  7  height =    2000.00`
	`  8  height =    3000.00`
	`  9  height =    4000.00`
	` 10  height =    5000.00`
	` 11  height =    6000.00`
	` 12  height =    7000.00`
	` 13  height =    8000.00`
	` 14  height =    9000.00`
	` 15  height =   10000.00`

[3]	`m =  2  time slice =  1`
[4]	`Grid point (x,y,lon,lat):   3   3   -78.00000  39.00000`

[5]	`0     976.299988     Pressure`
	`1     964.200012`
	`2     946.299988`
	`3     917.299988`
	`4     889.000000`
	`5     861.400024`
	`6     808.200012`
	`7     757.700012`
	`8     664.200012`
	`9     580.200012`

[6]	`0     274.299988     Temperature`
	`1     274.000000`
	`2     273.600006`
	`3     272.799988`
	`4     271.399994`
	`5     269.200012`
	`6     265.600006`
	`7     262.500000`
	`8     255.500000`
	`9     249.899994`

Table 5 Parts of the output from *metascii2metgm_nt* for 1 grid point showing [7] u wind component (ms^{-1}) for the first 10 data levels; [8] v wind component (ms^{-1}) for the first 10 data levels; and [9] sea level pressure (hPa) with the data level indicated as 0 (sea level). Note that the nominal precision of many of the listed values (5, 6, or more places to the right of the decimal point) is copied from the METGM file and does not represent actual precision or accuracy. Data section numbers and labels in the table are for clarity and do not appear in the output.

[7]	0	3.09999990	U wind component
	1	5.00000000	
	2	8.10000038	
	3	13.1999998	
	4	16.0000000	
	5	16.5000000	
	6	17.2000008	
	7	20.0000000	
	8	17.7000008	
	9	22.1000004	
[8]	0	-0.300000012	V wind component
	1	-1.60000002	
	2	-3.70000005	
	3	-7.19999981	
	4	-9.10000038	
	5	-9.50000000	
	6	-9.00000000	
	7	-7.80000019	
	8	-3.59999990	
	9	-7.19999981	
[9]	0	976.299988	Surface pressure

5. Comparisons with Model Profiles

Vertical profiles of MET variables extracted from a METGM using *readmetgm* may be compared to profiles taken directly from the initial GFS or GALWEM file used as input to the software. The scripts and programs that obtain a vertical profile from GFS or GALWEM output files are described in Cogan (2019b, 2017).

Several locations were included in this brief comparison. They are a location near Washington, DC, another near the border between Texas and Louisiana (Toledo Bend Reservoir), one over a Hawaiian island and adjacent ocean, and one near the center of New Mexico. The outcomes using GALWEM and GFS appear consistent for those sites for several days in November and December 2019. The days and model start times were 18, 20, and 26 November at 00, 12, and 00 Coordinated Universal Time (UTC), respectively, and 5 December at 00 UTC. Mostly files for the 3-h forecast were used although quick looks were made with 0- and 6-h forecasts. A grid interval of 0.25° was selected for the smaller GRIB2 file produced from the input GFS or GALWEM file as well as for the METGMs. The 0.25° interval matches that of the GFS and GALWEM output files, and therefore minimizes the need for horizontal interpolation.

In general, the METGM profiles derived from GALWEM data were close to those extracted directly from the model output using the method described in Cogan (2017). However, the profiles derived from GFS data often deviated from the respective ones produced directly from the model output for relative humidity and the u and v wind components. The METGM pressure profiles derived from GFS were fairly close to the respective ones directly extracted from the GFS output files and generally were fairly close for temperature, but occasionally exceeded 1 K at one or more levels. The differences between profiles derived from GALWEM only varied to a minor extent for different grid sizes of the domain of the smaller GRIB2 file used to create the METGM, but those from GFS exhibited noticeable differences for the horizontal wind components as well as for relative humidity. For example, for the East Coast location on 20 November (3-h forecast from 12 UTC model start) the differences in the u component of the wind were small between the profile extracted directly from the GFS output file and the respective one from the METGM produced from the 3 × 3 grid point GRIB2 file extracted from the GFS output file using wgrib2. However, the differences were much larger for many heights between the directly extracted profile and the respective profile from a METGM created from the 21 × 21 grid point GRIB2 file extracted from the GFS output file. Figure 2 shows the results for this example.

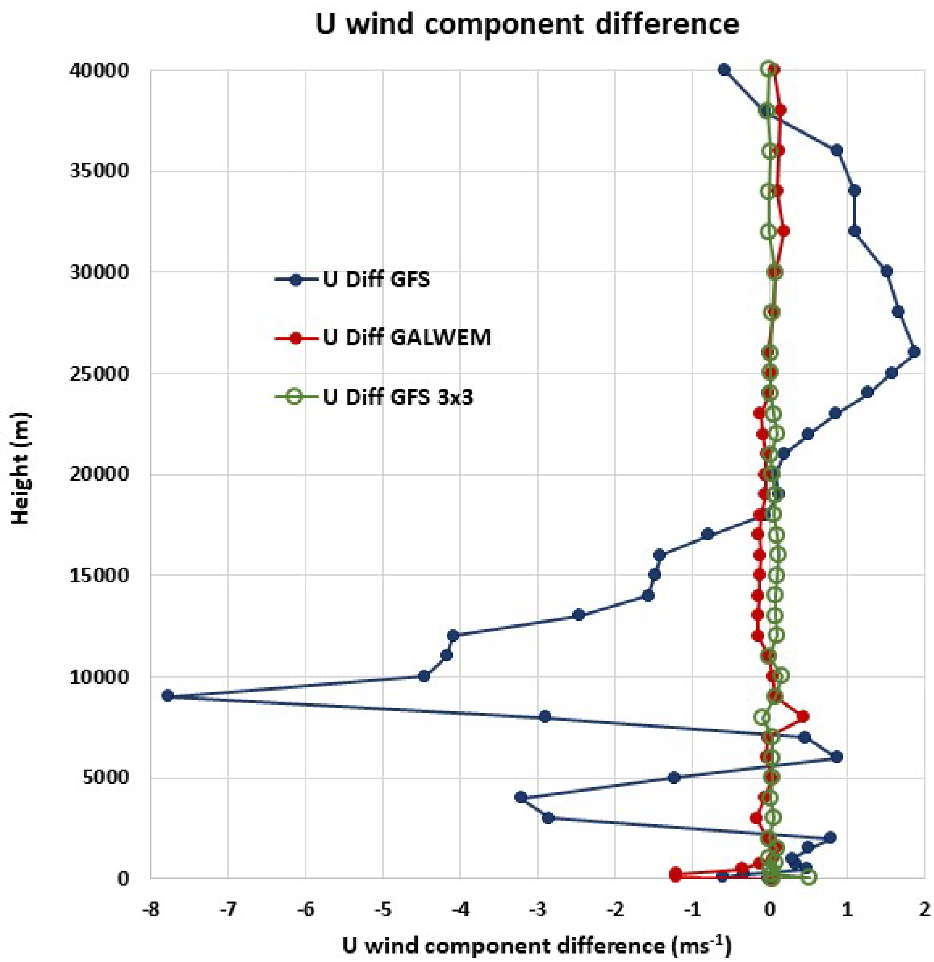

Fig. 2 Difference in U component of wind (METGM value minus value extracted directly from initial input GFS or GALWEM file) for the 3-h GALWEM and GFS forecasts on 20 November 2019 with a model start at 12 UTC. The location (–77.0, 39.0) was close to Washington, DC. The GRIB2 files, extracted from the global models, used to create the METGMs had 21 × 21 grid points with a 0.25° interval, except that the smaller file extracted from GFS had 3 × 3 grid points with a 0.25° interval.

For the v wind component, the situation was much the same although the magnitude of the maximum difference was somewhat less, –5.45 ms^{-1} instead of –7.77 ms^{-1}. The magnitudes of the pressure differences were similar for the METGM profiles derived from GFS and GALWEM. Figure 3 presents an example for the same location and time as in Fig. 2.

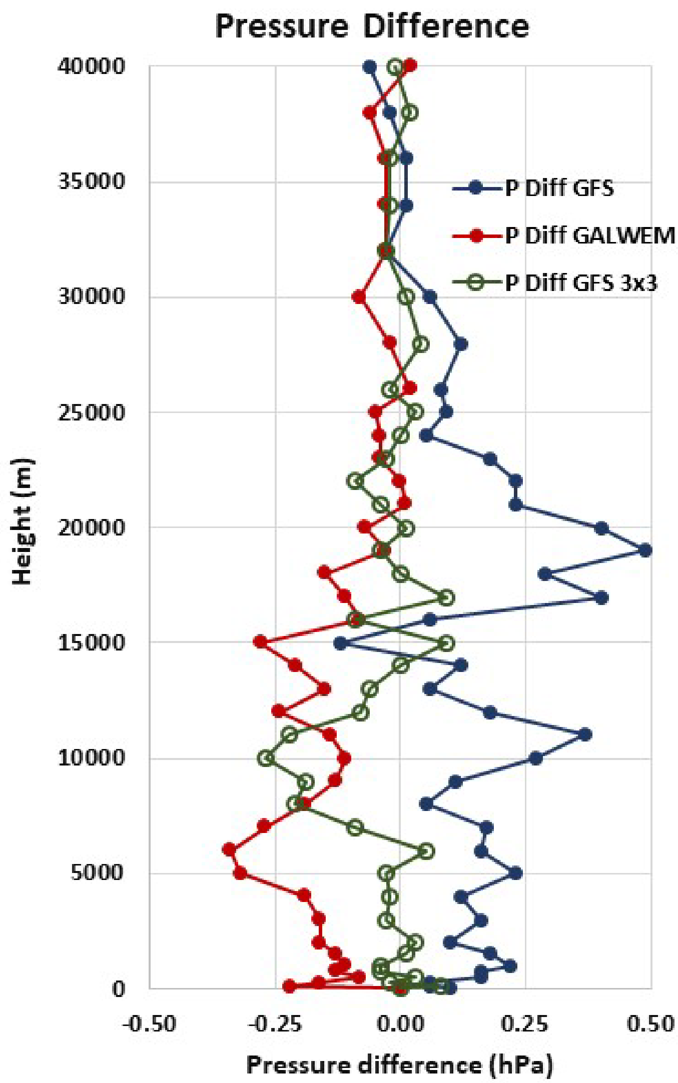

Fig. 3 Pressure differences for the same location and time of the data for Fig. 2

As with the u and v wind components, the temperature differences were reasonable between the profile from the METGM created from the GRIB2 file taken from the GALWEM output file versus the respective profile extracted directly from the GALWEM output, as well as for the profile from the METGM produced from the 3 × 3 grid point GRIB2 file from the GFS output versus the profile extracted directly from the GFS output. However, the differences were considerably larger for the METGM created from the 21 × 21 grid point GRIB2 file taken from the GFS output file versus the respective profile directly extracted from that GFS file. Figure 4 has an example for differences in temperature.

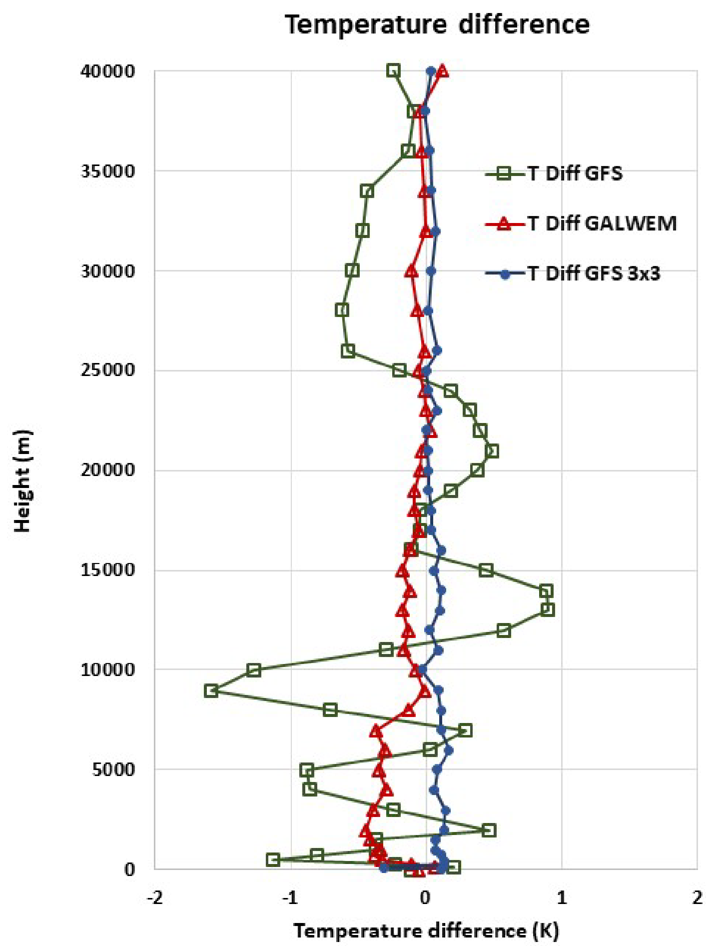

Fig. 4 Temperature differences for the same location and time of the data for Fig. 2

Comparisons were made using METGMs from the other sites and times as well. Overall, the differences in all variables except pressure using GFS as input were large at some levels. The differences were larger for more complex terrain, especially for the u and wind components and for relative humidity. The differences in the u component, for example, had a maximum of about 16 ms^{-1} at 7 km AGL (surface height of ~1800 m MSL) for the New Mexico location. On the other hand, for the Hawaii location, the maximum magnitude of the u difference was only about 0.7 ms^{-1} at 13 km AGL.

6. Additional Application

The aforementioned method to obtain a METGM from GRIB2 data appears useful under certain circumstances, but not in others. Obtaining a METGM from GALWEM output seems reasonable based on the limited sample examined for this report. However, a NATO-sponsored software product is able to generate a METGM that has MET profiles that very closely match the respective ones derived directly from the input GALWEM file. Currently, the same capability is not available for GFS output. From the limited GFS sample of this report, it appears that extracting a very small GRIB2 file (e.g., 3 × 3 horizontal grid points) from the global GFS output file can lead to a METGM with vertical profiles that closely match those of the input GFS file. However the METGM would have limited usefulness.

Nevertheless, the method generates intermediate text files that contain sounding information for user-defined grid sizes and intervals. Those files may be used "as is" or modified to generate model output soundings that may be compared with observations or with soundings produced by other models. Table 6 shows part of the temperature and surface pressure listings for the first and second grid point of the text output from a modified version of *gfs2text.py*. It illustrates a relatively modest change to the output format, but more extensive ones could be made in accordance with the application.

Table 6 Sample of output similar in format to that presented in Table 2, but with *gfs2text.py* modified to produce output that has each profile preceded by its longitude and latitude. A sample of temperature data are shown for the listed latitude and longitude points (1) followed by the surface pressures for the same two points (2). Section numbers and labels are for clarity and do not appear in the output.

	-79.0000	38.0000	Longitude, latitude
	275.082		Temperature
	274.479		
	272.491		
	268.645		
	265.319		
	262.253		
	258.928		
	.		
	.		
	.		
	220.190		
(1)	223.679		
	226.700		
	233.583		
	240.000		
	251.400		
	-78.7500	38.0000	
	276.282		
	273.979		
	272.091		
	268.745		
	.		
	.		
	.		
	-79.0000	38.0000	
(2)	943.590		Surface pressure
	-78.7500	38.0000	
	963.542		

7. Conclusion

This report describes a method to produce a METGM from a GFS or GALWEM output file. The resultant METGM is in the older Edition 1 format, but an existing NATO program may be used to convert it into the newer Edition 2 format that is currently in use. Both METGM versions were tested using the GTRAJ trajectory simulator program and GTRAJ ran successfully using either one. In terms of the ability to replicate the relevant MET vertical profiles in the input GFS or GALWEM output files, the resultant METGMs varied significantly. The testing to date, though limited, suggests that with GALWEM input the method replicates the input to a useful accuracy, but with GFS input it is less precise. Over complex terrain, the scripts and program perform even less accurately, especially when using a GFS input file. Interestingly, if the included wgrib2 program extracts a small GRIB2 file from the global GFS input (e.g., 3 × 3 grid points) from which to create the METGM, the method appears to work well. This result is in contrast to the result when a larger GRIB2 file is used (e.g., 21 × 21 grid points). The greater differences for larger files extracted from the GFS output appear to be related to the interpolation methods within the FORTRAN program and the smoothness of the parent GFS and GALWEM output. Determination of the effect, if any, of those or other factors are beyond the scope of this short report. Future work may address this issue. Although use of this software for an operational application is not recommended, it may provide a useful backup to the NATO software if extracting METGMs from GALWEM files.

8. References

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9. Additional Resources

The following sites and their included links contain information on wgrib2:

- https://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/
- https://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/short_cmd_list.html

The following sites and their included links have information on GFS output:

- https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs
- https://www.nco.ncep.noaa.gov/pmb/products/gfs/

List of Symbols, Abbreviations, and Acronyms

3-D	3-dimensional
4-D	4-dimensional
AGL	above ground level
ARL	Army Research Laboratory
CCDC	US Army Combat Capabilities Development Command
GALWEM	Global Air Land Weather Exploitation Model
GFS	Global Forecast System
HGT	height
MET	meteorological
METGM	Gridded Meteorological Message
MTERH	terrain height variable
NATO	North Atlantic Treaty Organization
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NWP	numerical weather prediction
PRMSL	pressure at mean sea level
UGRD	u wind component
UM	Unified Model
UTC	Coordinated Universal Time
VGRD	v wind component
WRF	Weather Research and Forecasting

1 (PDF)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA
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