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Extraction of Multiple Soundings from Model Output Files

by J Cogan

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14. ABSTRACT

Evaluation of numerical weather prediction models commonly considers the surface and near-surface layers. Comprehensive and sophisticated statistical packages are available that can generate a variety of statistical measures, although they mostly consider the surface, near surface, and a limited number of higher levels, mainly within or near the boundary layer or at standard pressure levels. An earlier report presented several scripts and programs that may assist in a more complete evaluation of model performance. The software is able to extract vertical soundings from the output of several representative models, including the Global Forecast System, the Global Air Land Weather Exploitation Model, and the Weather Research and Forecast model, and can evaluate single or multiple soundings from the model output. This brief follow-on report extends the means to extract vertical soundings from model output files to include multiple soundings at user-defined horizontal intervals along a user-defined azimuth up to and including a user-defined maximum distance, as well as provides additional flexibility with respect to the output of soundings with user-defined level and layer structures based on height, pressure, or both. The added flexibility also is applied to radiosonde data.

15. SUBJECT TERMS

model evaluation, vertical profile extraction, multiple sounding extraction, user-defined sounding structures

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1. Introduction

Evaluation of numerical weather prediction (NWP) models on finer scales commonly considers the surface and near-surface layers where a larger number of observations are available, often in greater detail relative to upper air measurements. For larger-scale models, such as those run at weather centers, publically available comparisons mostly consider data at certain standard levels at set time intervals. The following websites were provided in my previous report (Cogan 2018), but are summarized here for convenience. The National Center for Environmental Prediction (NCEP; http://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/) and the European Centre for Medium-Range Weather Forecasting (ECMWF; https://www.ecmwf.int/en/forecasts/charts/catalogue/) have readily accessible verification websites. Worldwide comparisons are available for deterministic forecasts at the ECMWF (http://apps.ecmwf.int/wmolcdnv/) and for ensemble forecasts at the Japan Meteorological Agency (http://epsv.kishou.go.jp/EPSv/). Comprehensive and sophisticated statistical packages with extensive user guides are available, such as the Model Evaluation Tool. They may be accessed at the Weather Research and Forecasting model (WRF) Developmental Test Center, http://www.dtcenter.org/met/ users/ and http://www.dtcenter.org/upp/users/. Similar tools are available at other centers such as NCEP.

NWP model output is frequently compared with radiosonde observations, where the entire sounding is often referred to using the acronym for radiosonde observation (RAOB). Ingleby et al. (2018) and their included references have up-to-date information on available RAOB data. Verification websites at major weather centers mostly present comparisons of model output for levels above the surface with data from RAOBs. Many field tests involve comparisons of output from finer-scale models such as the WRF model (herein WRF) with RAOB data (e.g., Dutsch [2012] and Kilpelainen et al. [2012]). Skamarock et al. (2008) describe details of the WRF, and despite the upgrades since then, the basics remain much the same. Details on output products from the Global Forecast System (GFS), as used at the National Oceanic and Atmospheric Agency (NOAA), are available at http://www.nco.ncep.noaa.gov/pmb/products/ and http://www.nco.ncep.noaa.gov/pmb/products/gfs/#GFS, and via included links. The Global Air Land Weather Exploitation Model (GALWEM) has no similar readily available website. However, GALWEM is a version of the UK Met Office's Unified Model, which has a public website that contains overviews of the model and its application (https://www.metoffice.gov.uk/research/modelling-systems/unified-model).

This report extends the set of scripts and programs presented in Cogan (2018) that allow the user to easily extract vertical profiles of meteorological variables from GFS and GALWEM output in Gridded Binary (GRIB2) format and vertical profiles from WRF output in netCDF format. The software allows the user to convert the extracted profiles into "soundings" with a height or pressure level or layer structure as defined by the user. A RAOB sounding also can be converted into forms having user-defined height or pressure levels or layers. Here I present a modified version of the software for extraction of vertical profiles that has additional capabilities that allow for soundings for multiple locations as defined by the user at horizontal intervals along an azimuth up to and including a user-selected maximum distance. As before, those profiles may include wind speed and direction plus virtual temperature (T_v) or u and v wind components plus relative humidity (RH). Both forms have temperature and pressure (or height) for the respective height-based (or pressure-based) profiles. Additionally, other combinations of output variables may be provided on request such as files with u and v components and T_v.

The Bash scripts for the model as well as the RAOB output presented in this report also allow additional flexibility in output by enabling one or both types of soundings (e.g., u, v, or wind speed and direction) for user-defined level and layer structures based on height, pressure, or both; that is, one to all optional forms of output may be selected by the user. The underlying wgrib2 commands, Python 3 scripts, US National Center for Atmospheric Research Command Language (NCL) script (Reen 2017), and C programs remain as before, except that a short Python 3 script was written to help define the sounding locations from the model output and a requested modification to the output required a few minor code changes to the output section of a C program.

2. Scripts

Bash scripts were developed earlier for extraction of vertical soundings from global (GFS and GALWEM) and mesoscale (WRF) model output (wgrb2.sh and wrf_extract.sh) and conversion into one of two types of output tables based on either height- or pressure-based user-defined level and layer structures. Another script converted a RAOB to soundings at user-defined height or pressure levels and layers. These scripts were extended as discussed in the following subsections. Appendix A contains flowcharts for the Bash scripts described in Section 2.1 (wgrb2_ma.sh) and Section 2.2 (wrf_extract_ma.sh). Appendix B has brief descriptions along with attached code listings for the extended scripts and the additional Python 3 script. Additionally, a modified version of wgrb2.sh was written in response to a user request. This modified version is briefly described in Section 2.3.

2.1 Script for GRIB2 Input

A variation of the Bash script for extraction of soundings from GRIB2 data was developed to enable the processing for multiple locations at set intervals from a specific user-selected initial or base site in a user-defined direction from that site in degrees from true north up to and including a user-set maximum distance. It also allows for the user to output one of the user-defined optional types (e.g., wind components for pressure levels and layers), some combination of output types, or all of them.

This version of the script is executed by entering its name:

./wgrb2_ma.sh

The "_ma" refers to multiple soundings (m) for one to all output types (a). As with wgrb2.sh, the user is asked for the file and path names. The script contains default values for the number of grid points in the horizontal (x, y) directions and the grid spacing, 2 and 0.00001°, respectively, but the user has the option of choosing other values. This default horizontal grid interval is roughly equivalent to 1 m. The user also enters the interval in kilometers between profile extraction locations (e.g., 10), the direction of consecutive locations in degrees (e.g., 140), and the maximum distance in kilometers (e.g., 50). The maximum distance should be some integer multiple of the interval. If 0 is chosen for the interval, the script skips the entry of direction and maximum distance and only extracts the profile for the base site.

The output files have the same format as those produced using wgrb2.sh, but the distance from the base site in kilometers also is included in the filename (distance = interval × number of the iteration). For example, if the filename of the output from the wgrib2 commands is TestRun and the interval is 10 km then the first iteration will produce output with a filename of TestRun_0km_out, the second TestRun_10km_out, and so on to the maximum distance chosen by the user (e.g., TestRun_60km_out, which is the 7th iteration). The iterations start with the user-selected site and progress according to the user-selected interval and direction up to the user-chosen maximum distance. However, since an interval of 0 defaults to extraction of a profile for the site alone, wgrb2_ma.sh and wgrb2.sh will produce the same sounding in that case for the same GFS or GALWEM output file.

Following the extraction of the sounding and conversion to a tabular form (the "_out" file), the user optionally may either exit the program or generate soundings with user-defined level and layer height- and/or pressure-based structures. If output of soundings with user-defined structures is chosen, the user may select one to all available options (i.e., output files for wind speed and direction and T_v for height and pressure levels and layers plus u, v wind components and RH for height and pressure levels and layers).

2.2 Script for netCDF (WRF) Input

Similarly to the modification of the Bash script for processing GRIB2 output files, the Bash script for processing netCDF (i.e., WRF) files was changed to enable the processing of multiple locations at set intervals from a specific user-selected initial or base site in a user-defined direction from that site in degrees from true north up to and including a user-set maximum distance. It also allows for the user to output one of the user-defined optional types (e.g., wind components for pressure levels and layers), a combination of output types, or all of them.

This version of the script is run by entering its name:

```
./wrf_extract_ma.sh
```

Again, "_ma" refers to multiple soundings (m) for one to all output types (a). As with wrf_extract.sh, the user is asked for the file and path names. The user also types in the interval in kilometers between profile extraction locations, the direction of consecutive locations in degrees, and the maximum distance in kilometers. The maximum distance should be some integer multiple of the interval. If 0 is chosen for the interval, the script skips the entry of direction and maximum distance and only extracts the profile for the base site.

The output files have the same format as those produced using wrf_extract.sh, but the distance from the base site in kilometers also is included in the filename as with wgrb2_ma.sh. For example, if the filename of the output from the included NCL script is WRFtest and the interval is 10 km then the first iteration will produce output with a filename of WRFtest_0km, the second WRFtest_10km, and so on to the maximum distance chosen by the user (e.g., WRFtest_60km, which is the 7th iteration). The iterations start with the user-selected site and progress according to the user-selected interval and direction up to the chosen maximum distance. Since an interval of 0 defaults to extraction of a profile for the site alone, wrf_extract_ma.sh and wrf_extract.sh will produce the same sounding in this case for the same WRF output file.

Following the extraction of the sounding, the user optionally may either exit the program or generate level and layer height- and/or pressure-based profiles. Similarly as with wgrb2_ma.sh, the user may select one to all available options (i.e., output files for wind speed and direction and T_v for height and pressure levels and layers as well as u, v wind components and RH for height and pressure levels and layers).

2.3 Other Modified Scripts

A short Python 3 script, latlondist.py, was written to compute distance increments and the maximum distance in terms of latitude and longitude from user input in kilometers. The parent Bash script, or the user if run independently, enters input on the command line following the program name. The input parameters are latitude and longitude in decimal degrees (west longitude and south latitude use the convention of a negative value), the increment in kilometers, and the direction in decimal degrees from north. The Bash script first computes the latitude increment and then uses the average of the start and end latitudes of that increment (e.g., 30.5° for an increment of 0.2° that starts at 30.4° and ends at 30.6°) in the computation of the longitude increment. While use of the mean latitude versus the start (or end) latitude may not be significant for a short increment, it may be for a longer one since the increment in terms of longitude changes with latitude.

The script is executed as follows:

```
python3 latlondist.py LAT LON DIST DIR
```

where LAT, LON, DIST, and DIR are latitude, longitude, distance, and direction. The parent Bash script provides the input values, though the script may be run separately. The output is a single line in a text file named latlondist with the latitude and longitude increment, respectively. A sample command line is

```
python3 latlondist.py 38.5 -105.4 20 290
```

and the output in the file latlondist is 0.0616° latitude and –0.2163° longitude. Also, by typing "–h" after the program name (i.e., python3 latlondist.py –h) information on the program and input parameters will be printed to the screen.

The script for conversion of a RAOB into a sounding with a user-defined structure was modified to allow for more flexibility in the output. Similarly as with wgrb2_ma.sh and wrf_extract_ma.sh, the user may select one to all available options (i.e., output files for wind speed and direction and T_v for height and pressure levels and layers plus u, v wind components and RH for height and pressure levels and layers).

This version of the script is executed by entering its name:

```
./raob_a.sh
```

The "_a" refers to the version for one to all output types.

An additional version of the wgrb2.sh script described in my previous report (2018) was developed on request. It generates soundings with a user-defined, height-based structure only since no pressure-based sounding was needed for the application. It is similar to wgrb2.sh without the option for a sounding with a user-defined pressure based structure. Only one type of height-based output file is generated since the user requested one specific type, that is, wind component and T_v values in the output (vs. horizontal wind components and RH). Consequently, the output routine of the C program for converting a RAOB to a sounding with a user-defined height structure was slightly modified to produce tables with T_v instead of RH.

This additional version also is executed by entering its name:

./wgrb2_sp.sh

The "_sp" refers to the "special" version. The called C program is a slightly modified version of convertgfs (see Cogan [2018]) named convertgfsj.

3. Output

The output files from wgrb2_ma.sh have the same formats as that from wgrb2.sh (Cogan 2018), but one or more output files of each type are produced depending on the chosen horizontal distance interval and the maximum distance from the base site. The files produced by wrf_extract_ma.sh have the same formats as from wrf_extract.sh, but again several of each type are generated depending on the interval and maximum distance.

Table 1 presents 10 of 302 lines of output extracted by wgrb2_ma.sh for a vertical profile from a GALWEM file using the called wgrib2 commands. The location was 20 km from Dulles Airport in Virginia at an azimuth of 200° from true north. The GALWEM file contained data for the 3-h forecast for an integration with a model start time of 12 Coordinate Universal Time (UTC) on 7 January 2019. Vertical profiles extracted from GFS output have nearly the same format

Table 1 Ten of 302 data lines of the vertical profile extracted from a GALWEM output file for a location 20 km from Dulles Airport, Virginia, at an azimuth of 200°. The data were for the 3-h forecast for a model integration starting at 12 UTC on 7 January 2019.

```
172:35910:d=2019010712:VGRD V-Component of Wind [m/s]:3 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=8.00578
173:36120:d=2019010712:UGRD U-Component of Wind [m/s]:2 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=64.545
174:36330:d=2019010712:VGRD V-Component of Wind [m/s]:2 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=11.8519
175:36540:d=2019010712:UGRD U-Component of Wind [m/s]:1 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=69.8118
176:36750:d=2019010712:VGRD V-Component of Wind [m/s]:1 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=7.84904
177:36960:d=2019010712:UGRD U-Component of Wind [m/s]:0 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=67.5217
178:37170:d=2019010712:VGRD V-Component of Wind [m/s]:0 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=-0.555898
179:37380:d=2019010712:HGT Geopotential Height [gpm]:1013 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=157.844
180:37590:d=2019010712:HGT Geopotential Height [gpm]:1000 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=261
181:37800:d=2019010712:HGT Geopotential Height [gpm]:975 mb:3 hour
fcst::lon=282.460800,lat=38.810700,i=1,ix=1,iy=1,val=462.962
```

Table 2 presents the output from the called Python 3 script gg_wg2.sh (Cogan 2018) that converts the very wordy output produced using wgrib2 into a more user-friendly form that also is more easily processed into a sounding with a user-defined vertical structure. At this time, that Python 3 script only lists variables of interest for current and planned applications, but other variables in the wgrib2-generated output file could be processed as needed.

Table 2 Header information and data lines extracted from the profile presented in part in Table 1. Only the first 11 data lines are shown. P is pressure, Hgt is height above mean sea level (MSL), Tmp is temperature, RH is relative humidity, U is the east–west component of the wind, and V is the north–south component. The units are as listed.

```
 3 hour   forecast after model start at: 2019010712

 Latitude:  38.811   Longitude:  -77.539

 P (hPa)  Hgt (m) Tmp (K)   RH (%)  U (m/s) V (m/s)
  1018.9    111.1  274.29    58.3   -2.39   -0.44
  1013.0    157.8  273.53    58.4   -3.50   -0.67
  1000.0    261.0  272.51    60.2   -4.01   -0.73
   975.0    463.0  270.61    64.7   -4.05   -0.64
   950.0    668.0  269.78    48.1   -3.63   -0.25
   925.0    879.8  271.64    21.6   -2.41    0.98
   900.0   1098.6  274.13     6.4   -1.27    1.80
   875.0   1325.6  275.73     1.2    0.84    2.18
   850.0   1559.6  276.58     1.5    2.55    2.00
   825.0   1801.4  276.33     1.8    3.14    1.50
   800.0   2049.4  275.01    10.2    3.45    0.51
```

Table 3 presents a sounding extracted from the 12-h forecast output of a WRF integration. The model started at 00 UTC on 9 November 2018. The sounding is for a location 30 km from Dulles Airport, Virginia, along an azimuth of 245° from the airport. The header contains the requested latitude and longitude in degrees, elevation in meters MSL, date and time string extracted from the input filename, horizontal grid spacing in meters, latitude and longitude of the profile, and a number indicating the selected interpolation method. The latitude and longitude of the requested and computed locations are the same for the inverse distance weighting (option 1) and bilinear (option 2) interpolations. However, they are different if there is no interpolation, that is, extraction of the grid point nearest to the requested location (option 0).

Table 3 Sounding extracted from the 12-h forecast output of a WRF integration starting at 00 UTC on 9 November 2018 for a location 30 km from Dulles Airport, Virginia, at an azimuth of 245°. The first 15 data lines are shown. The first header line contains the requested latitude and longitude in decimal degrees, elevation in meters, and the date and time string extracted from the input filename. The second header line has horizontal grid spacing in meters, latitude and longitude of the profile, and a number indicating the selected interpolation method. Each data line has height in meters MSL, pressure in hPa, temperature in °C, RH in %, wind speed in ms^{-1}, and wind direction in degrees.

```
 38.8658   77.7748    190.03 2018-11-09_12:00:00
  3000.0   38.8658   -77.7748    2
    190.03 1001.08     6.01    71.91     0.86   106.76
    201.74   999.43    5.96    68.82     0.86   106.96
    233.03   995.62    6.01    65.31     3.45   107.23
    280.15   989.90    5.78    63.39     5.16   104.91
    335.38   983.23    5.39    62.52     6.37   103.21
    398.88   975.62    4.89    62.51     7.39   102.25
    470.74   967.05    4.39    63.52     8.58   102.64
    547.20   958.00    4.11    66.51    10.18   105.09
    636.66   947.52    4.05    75.15    11.90   110.24
    739.58   935.61    3.99    88.35    13.39   118.34
    856.48   922.26    3.66    98.19    14.19   127.87
    987.67   907.46    3.09    95.34    13.97   136.02
   1133.69   891.25    2.67    81.06    12.55   144.41
   1295.29   873.62    2.72    63.95    11.19   153.97
   1478.23   854.11    3.16    42.45    11.26   152.74
```

The output profiles from wgrb2_ma.sh and wrf_extract_ma.sh, as well as a RAOB sounding from the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html) or the NOAA archive (https://ruc.noaa.gov/raobs/), may be converted into soundings with one or more of the several user-defined structures as noted in Section 2. The output formats are the same as presented in my earlier report (Cogan 2018). The height or pressure level and layer structures are defined by the parameter files usrhgt_lvls and usrprs_lvls, respectively. Here we present a sample from wgrb2_ma.sh and another from wrf_extract_ma.sh (Tables 4 and 5, respectively).

Table 4 Sounding with wind speed, wind direction, and T_v derived from GALWEM output for the same location and time as Table 1, and with a user-defined vertical height structure as defined in the file usrhgt_lvls. The first 15 data lines are shown. Layer weighted mean values are shown along with the midpoint heights above ground level (AGL), except for the surface (layer 0), which has the model output surface values. "Date:" has the date–time group from the input file, Elevation is in m MSL, Latitude and Longitude are in decimal degrees, and the values for Ceiling and Visibility are place holders (-999 means missing data) for possible future use. Wind_Dir is wind direction and Virt_Temp is T_v. The units are as shown.

```
USER DEFINED MODEL LAYER OUTPUT

Date: 2019010712  Time: 3  Latitude: 38.811  Longitude: -77.539
Elevation:  111.10     Ceiling:  -999.0     Visibility:  -999.0

Layer Height Wind_Dir  Wind_Speed Virt_Temp Pressure Temperature
        (m)  (degrees)     (kn)        (K)      (hPa)       (K)

  0      0.0    79.6      4.72      274.68   1018.90    274.29
  1    100.0    79.5      7.18      273.41   1006.27    273.04
  2    350.0    81.6      7.80      271.15    975.09    270.82
  3    750.0   107.0      5.15      271.81    927.21    271.66
  4   1250.0   206.0      4.41      275.71    871.16    275.69
  5   1750.0   249.2      6.62      275.90    818.91    275.85
  6   2250.0   257.8     10.67      273.16    769.50    272.92
  7   2750.0   254.4     23.48      271.51    722.73    271.20
  8   3250.0   270.1     35.70      269.62    678.38    269.25
  9   3750.0   282.6     44.89      266.90    636.60    266.48
 10   4250.0   289.4     46.51      264.11    596.97    263.69
 11   4750.0   294.8     47.51      262.28    559.44    261.88
 12   5500.0   292.1     59.74      260.74    507.11    260.34
 13   6500.0   290.5     69.97      257.04    444.63    256.72
 14   7500.0   291.2     68.68      250.61    388.60    250.43
```

Table 5 Sounding with wind components and RH derived from WRF output for the same location and model time as Table 3 with a user-defined vertical pressure level structure as defined in the file usrprs_lvls. Data values for the listed pressure levels are shown along with the heights AGL. The first 15 data lines are shown. U-wind and V-wind are the horizontal wind components. Rel-Humidity is RH. The units are as displayed. The header information has the same meanings as in Table 4.

```
USER DEFINED PRESSURE LEVEL OUTPUT (MODEL)

Date:2018-11-09 Time:12:00:00  Latitude:38.866 Longitude:-77.775
Elevation:  190.03     Ceiling:  -999.0     Visibility:  -999.0

Level Pressure  Height  U-wind  V-wind  Rel-Humidity Temperature
       (hPa)     (m)    (m/s)    (m/s)      (%)          (K)

  0    1001.1      0.0   -0.82    0.25     71.91       279.17
  1    1000.0      7.7   -0.82    0.25     69.89       279.14
  2     990.0     89.3   -4.96    1.32     63.42       278.94
  3     975.0    214.0   -7.30    1.59     62.58       278.01
  4     950.0    425.4  -10.85    3.77     73.10       277.22
  5     925.0    642.3  -11.32    8.22     96.16       276.89
  6     900.0    864.5   -8.60   10.12     88.80       276.06
  7     875.0   1092.5   -5.10   10.07     65.30       275.88
  8     850.0   1327.3   -5.20   10.12     42.38       276.36
  9     825.0   1569.5   -3.24   11.49     55.28       276.67
 10     800.0   1819.8    4.28   14.36     88.81       277.37
 11     775.0   2078.5   10.32   15.16    100.00       277.48
 12     750.0   2345.3   12.55   13.04    100.00       276.13
 13     725.0   2619.8   14.21   11.51     99.78       274.71
 14     700.0   2902.4   15.87   11.10     98.56       273.27
```

4. Conclusion

This brief report presents enhancements to a few of the Bash scripts presented in my earlier report (Cogan 2018). In addition, minor modifications to an earlier Bash script and a called C program were made as a result of a user request related to the application of the output. The two reports together provide a description of the overall set of scripts and programs that may be used to extract vertical profiles from GRIB2 (GFS and GALWEM) and netCDF (WRF) meteorological model output and compare them to soundings from RAOBs or with one another. Examples of the latter could include output from the same model running with different configurations such as with different physics packages or at different horizontal or vertical grid resolutions, or output from different models such as GFS and GALWEM. Nearly all of the C programs noted herein and in the previous report are available on the US Army Combat Capabilities Development Command Army Research Laboratory's GitHub site (https://github.com/usarmyresearchlab), and the others, including the Bash and Python 3 scripts and most of the NCL script, are available in this report or Cogan (2018).

5. References

Cogan J. Extraction and comparison of vertical profiles from global and mesoscale models. Adelphi Laboratory Center (MD): Army Research Laboratory (US); 2018 Dec. Report No.: ARL-TR-8589.

Dutsch ML. Evaluation of the WRF model based on observations made by controlled meteorological balloons in the atmospheric boundary layer of Svalbard. Bergen (Norway): Meteorologisk Institutt, Bergen; 2012.

Ingleby B, Isaksen L, Kral T, Haiden T, Dahoui M. Improved use of atmospheric in situ data. In: ECMWF Newsletter. 2018;155:20–25. doi:10.21957/cf724bi05s.

Kilpelainen T, Vihma T, Mannienen M, Sjoblom A, Jakobson E, Palo T, Maturilli M. Modelling the vertical structure of the atmospheric boundary layer over Arctic fjords in Svalbard. Q J R Meteorol Soc. 2012;138:1867–1883.

Reen B. Army Research Laboratory (US), Adelphi Laboratory Center, MD. Personal communication, 2017.

Skamarock WC, Klemp JB, Dudhia J, Gill DO, Barker DM, Duda MG, Huang X-Y, Wang W, Powers JG. A description of the Advanced Research WRF Version 3. Boulder (CO): National Center for Atmospheric Sciences; 2008. Report No.: NCAR/TN-475+STR.

Appendix A. Flowcharts for the Bash Scripts

This appendix appears in its original form without editorial change.

This Appendix contains flowcharts for the Bash scripts wgrb2_ma.sh and wrf_extract_ma.sh. They may be compared with those for wgrb2.sh and wrf_extract.sh in my earlier report.[1]

[1]Cogan J. Extraction and comparison of vertical profiles from global and mesoscale models. Adelphi Laboratory Center (MD): Army Research Laboratory; 2018 Dec. Report No.: ARL-TR-8589.

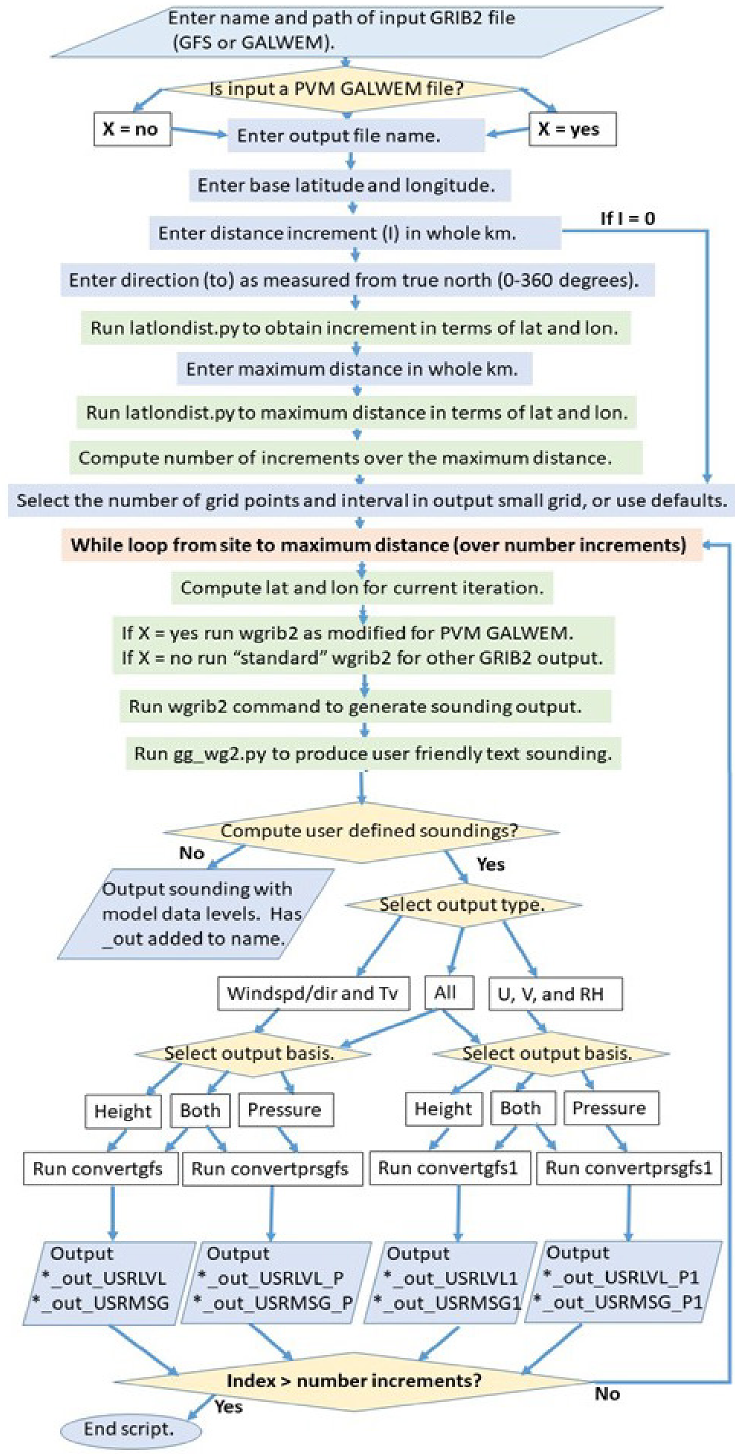

Fig. A-1 Flowchart of the Bash script wgrb2_ma.sh

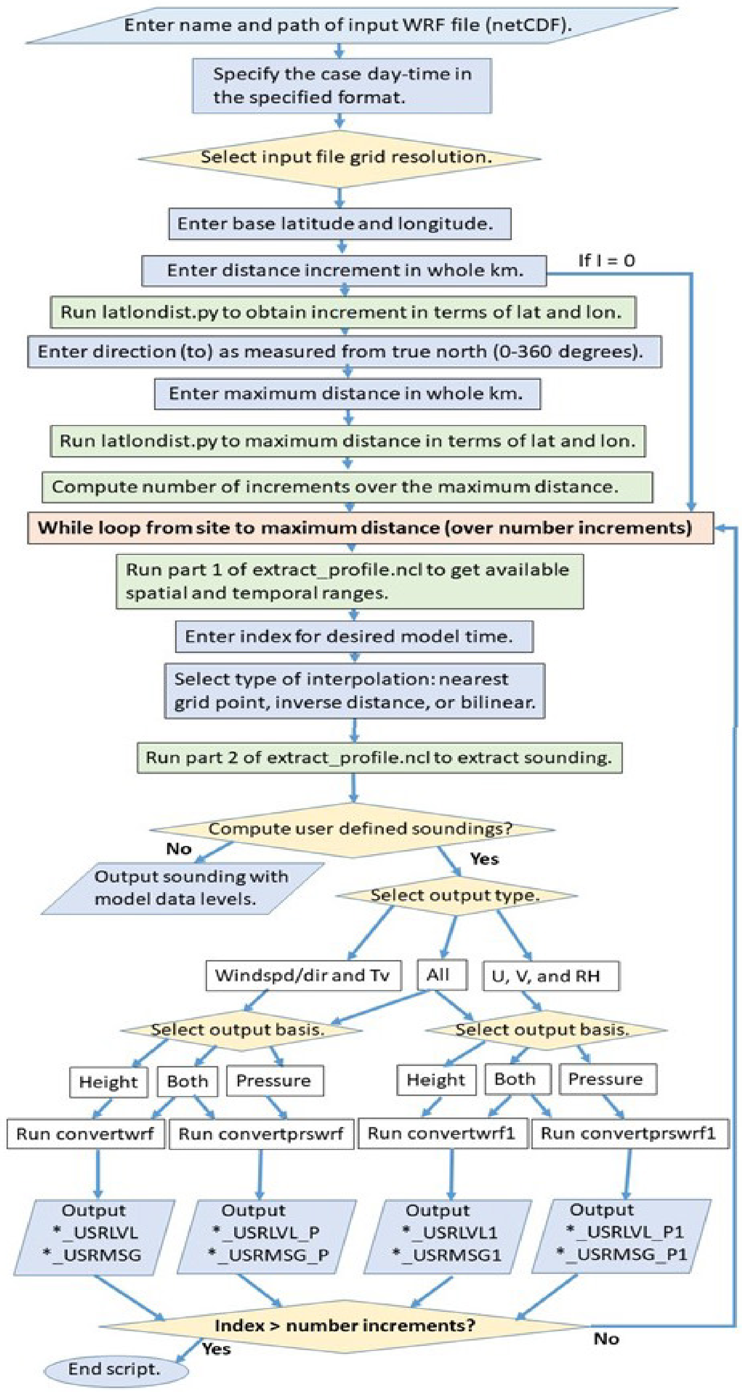

Fig. A-2 Flowchart of the Bash script wrf_extract_ma.sh

Appendix B. Extended Scripts and Additional Python 3 Script

The modified scripts wgrb2_ma.sh, wrf_extract_ma.sh, raob_a.sh, and latlondist.py are very briefly described in this Appendix and the respective listings in text format are attached.

wgrb2_ma.sh: Extracts one or more "soundings" from a Global Forecast System or Global Air Land Weather Exploitation Model output file and converts them to soundings with user height or pressure levels and layers. Includes options for the user. If 0 is chosen for the increment, then the sounding for the base site alone is extracted. In that case, the script will produce the same output as wgrb2.sh (single site only). The user may generate soundings with one to all of the optional combinations of output types and height and pressure level and layer structures.

wrf_extract_ma.sh: Extracts one or more soundings from a Weather Research and Forecasting output file and converts them to soundings with user height or pressure levels and layers. Includes options for the user. If 0 is chosen for the increment, then the sounding for the base site alone is extracted. In that case, the script will produce the same output as wrf_extract.sh (single site only). The user may generate soundings with one to all of the optional combinations of output types and height and pressure level and layer structures. The included US National Center for Atmospheric Research (NCAR) Command Language program was written by Reen[2] as were certain related parts of the Bash script.

raob_a.sh: Takes a radiosonde sounding from the University of Wyoming's weather website or from the National Oceanic and Atmospheric Agency archive website and converts it to forms with user height or pressure levels and layers. Includes options for the user. The user may generate soundings with one to all of the optional combinations of output types and height and pressure level and layer structures.

latlondist.py: Converts an input distance in kilometers to the equivalent increment in latitude and longitude in decimal degrees given input of initial latitude and longitude, distance in kilometers, and direction relative to true north from the initial site (i.e., azimuth). Used by wgrb2_ma.sh and wrf_extract_ma.sh, but may be used separately.

[2] Reen B. Army Research Laboratory, Adelphi Laboratory Center, MD. Personal communication, 2017.

List of Symbols, Abbreviations, and Acronyms

AGL	above ground level
ECMWF	European Centre for Medium-Range Weather Forecasting
GALWEM	Global Air Land Weather Exploitation Model
GFS	Global Forecast System
GRIB2	Gridded Binary
MSL	mean sea level
NCEP	National Center for Environmental Prediction
NCL	US National Center for Atmospheric Research Command Language
NOAA	National Oceanic and Atmospheric Agency
NWP	numerical weather prediction
RAOB	radiosonde observation
RH	relative humidity
T_v	virtual temperature
UTC	Coordinated Universal Time
WRF	Weather Research and Forecasting

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