METplus for Evaluation of WRF Meteorology

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METplus is a Python scripting infrastructure around the MET verification tools. The core components of the framework include MET, the associated database and display systems called METviewer and METexpress, and a suite of Python wrappers to provide low-level automation and examples, also called use-cases. For more information on MET and METplus see: https://dtcenter.org/community-code/metplus
As part of the AQE project, METplus has been configured to compare WRF to MADIS surface meteorological and NOAA GML surface radiation observations. The provided scripts will automatically download the observations.

Verification Description:

The following verification capabilities are set up for MADIS and NOAA data:

1. WRF surface variables compared to MADIS data
    a. Variables include 2-meter temperature, 2-meter dew point, 2-meter relative humidity, 10 meter wind, and surface pressure
    b. The verification is set up to run on the full WRF model domain and on a region over the Front Range. Additional regions can be added
2. WRF surface radiation compared to SURFRAD at the Table Mesa site
    a. Variables include downwelling shortwave, new shortwave, upwelling shortwave, downwelling clear sky shortwave, upwelling longwave, and downwelling longwave
    b. Since the SURFRAD data is a single point, this verification only runs over the full domain (changing domains will not change the results)
3. Display of the data and output statistics
    a. Contour plots showing the model values overlayed with the point observations on the same color scale
        i. 2 meter temperature, 2 meter dew point, 2 meter relative humidity, surface pressure
    b. Line plots showing the output statistics of Mean Error or bias (ME), Root Mean Squared Error (RMSE), and Mean Absolute Error (MAE) stratified by the hour of the day
        i. 2 meter temperature, 2 meter dew point, 2 meter relative humidity, surface pressure

ii. downwelling shortwave, new shortwave, upwelling shortwave, downwelling clear sky shortwave, upwelling longwave, and downwelling longwave

c. Wind Roses showing the observation and model wind speed, as well as their difference

Installation via conda

(Steps 1-6 are not needed if your machine has Chrome installed)

1. mkdir -p $HOME/chrome
2. cd $HOME/chrome
3. wget https://storage.googleapis.com/chromium-browser-snapshots/Linux_x64/1219122/chrome-linux.zip
4. unzip chrome-linux.zip
5. If you are in TCSH shell, please add the following in your ~/.tcshrc file,

   setenv PRE_LOAD_CHROME ${HOME}/chrome/chrome-linux/chrome

   setenv PATH ${HOME}/chrome/chrome-linux:${PATH}

   If you are using bash shell, please add the following in your ~/.bashrc file

   export PRE_LOAD_CHROME=${HOME}/chrome/chrome-linux/chrome

   export PATH=${HOME}/chrome/chrome-linux:${PATH}

6. conda create -y -n metplus_env python=3.10
7. conda activate metplus_env
8. conda install -y -c conda-forge metplus numpy scipy pandas xarray netCDF4 pyyaml lxml metpy plotly python-kaleido
9. Clone METplus v6.2 into your local directory
   ```
   git clone https://github.com/dtcenter/METplus
   cd METplus
   git checkout main_v6.2
   cd ..
   ```
10. Clone METploypy into your local directory
    ```
    git clone https://github.com/dtcenter/METplotpy
    cd METplotpy
    pip install -e . --no-deps
    cd ..
    ```
11. Clone METdataio into your local directory
    ```
    git clone https://github.com/dtcenter/METdataio
    cd METdataio
    ```

pip install -e . --no-deps
cd ..

12. Clone METcalcpy into your local directory
    git clone https://github.com/dtcenter/METcalcpy
    cd METcalcpy
    pip install -e . --no-deps
    cd ..
13. Checkout SIP specific configuration files and directories with python scripts and yaml files from https://github.com/NCAR/AQE_SIP_PROJECT. To checkout only the MetPlus folder use the following commands:
    git clone --no-checkout https://github.com/NCAR/AQE_SIP_PROJECT
    cd AQE_SIP_PROJECT/
    git sparse-checkout init --cone
    git sparse-checkout set MetPlus_SIP
    git checkout main
14. Continue by going to: Description of the Configuration files

Steps to Run the Verification:

1. Make edits to the configuration files
    a. Necessary edits are listed below for each configuration file
2. Run masks if desired using GenVxMask_fcstWRF_fcstOnly.conf
3. Run surface statistics and plots using PointStat_fcstWRF_obsMADIS_surface_pe.conf
4. Run radiation statistics and plots using PointStat_fcstWRF_obsSURFRAD_radiation.conf
5. Run model contour images with observation points overlaid using PlotPointObs_fcstWRF_obsMADIS_surface.conf (this step needs to be done last since it relies on the data ingest in step 5)

Description of the Configuration files

system.conf

- Contains the paths listed below as well as some variables that are used in multiple of the METplus configuration files

Variables you will need to change:

INPUT_BASE: The location of the input data on the system where this verification is run. It is best if all input data is stored in this same location. For example, as the

configuration is set up, the WRF model data is stored in a directory that is INPUT_BASE/WRF

OUTPUT_BASE: The location where you want to send output data. Make sure you have permission to write to this location.

MET_INSTALL_DIR: point to installed environment, e.g:
MET_INSTALL_DIR = /glade/work/pfister/conda-envs/metplus_env

CONF_DIR: The location where your METplus configuration files are located. The python_scripts and yaml_plotting_configurations directories should also be in this same location

MET_PYTHON_EXE: Contains the location of Python with all the needed packages that will be used both for computing statistics and creating graphics. Set this to the location of the Python you are using

GenVxMask_fcstWRF_fcstOnly.conf

- Runs GenVxMask to create a masking region for the front range domain. If you do not want to change or add additional masking regions, then this configuration does not need to be run. You will want to run this before any other verification if needed.

To add additional masks:

1. create a .poly file in the format below. It should have the latitude and longitude coordinates of the bounding box, as well as a name that you are giving to the masking region on the first line. Store this in the same place as Front_Range.poly ({INPUT_BASE}/masks). The location of this file should be specified as GEN_VX_MASK_INPUT_MASK_DIR
   Front_Range
   39.2 -105.4
   40.9 -105.4
   40.9 -103.8
   39.2 -103.8
2. Change the GEN_VX_MASK_INPUT_MASK_TEMPLATE and GEN_VX_MASK_OUTPUT_TEMPLATE in the configuration file to point to your new .poly file and an output mask file that will be created
3. Make sure that GEN_VX_MASK_INPUT_DIR is set to the location of your model data
4. Change the VALID_BEG and VALID_END. You only need to run the mask on a single time step, so these can be set to the same value, but they should be set to a model time that is available

5. The prefix of WRF output files is by default set to “d03”. Please change the WRF_DOMAIN variable if you have a different prefix for your WRF output data.
6. Create the mask by running the following command:
   run_metplus.py GenVxMask_fcstWRF_fcstOnly.conf system.conf

   Note that both “GenVxMask_fcstWRF_fcstOnly.conf” and “system.conf” must be passed to run_metplus.py. Also note that you may need to specify the full path to run_metplus.py (ex: /home/METplus/ush/run_metplus.py)

Output:

An output mask can be found in the directory specified in GEN_VX_MASK_OUTPUT_DIR. They will be named to the value set in GEN_VX_MASK_OUTPUT_TEMPLATE

PointStat_fcstWRF_obsMADIS_surface_pe.conf

- Runs data at hourly intervals starting on 07/20/2022 at 00 UTC and ending at 07/20/2022 23 UTC
- Downloads the observed MADIS data automatically for the days and times specified
- Computes statistics for surface temperature, dew point, relative humidity, wind, and surface pressure compared to MADIS data
- Creates line plots of ME, MAE, and RMSE over the FULL and Front Range domains
- Creates wind roses for WRF, MADIS, and a difference wind rose over the FULL and Front Range domains

To run these statistics:

1. Change the VALID_BEG and VALID_END to the start and end times of the data you want to verify and have available.
   a. If you need to edit the model increment (set to 1 hour), be sure to edit VALID_INCREMENT that falls below the line that reads [ps_radiation].
2. The prefix of WRF output files is by default set to “d03”. Please change the WRF_DOMAIN variable if you have a different prefix for your WRF output data.
3. Change the times listed in the yaml plotting configuration files located under the directory named yaml_configurations, custom_line_MAE_env.yaml, custom_line_ME_env.yaml, and custom_line_RMSE_env.yaml
   a. These dates should be set to the first day of the time period that you are verifying

    b. You can change the title and output plot name by editing the title and plot_filename variables inside these yaml files
4. If desired, add or change the masking regions using POINT_STAT_MASK_GRID and POINT_STAT_MASK_POLY
5. Make sure the fcst input and output directories point to your model data. Specifically, check the dates for the following variables:
    a. WIND_ROSE_STAT_INPUT_FILES
    b. MAP_CNT_FILE
    c. MAP_MPR_FILE
6. Make sure the obs input and output directories point to the location of the obs that were downloaded using the data ingest
7. Run the verification and plots by executing the following command: *run_metplus.py PointStat_fcstWRF_obsMADIS_surface_pe.conf system.conf*

Output:

Output files from Point-Stat contain the statistics for each day and time the data has run. They can be found in the directory OUTPUT_BASE/PointStat/surface/YYYYMMDD. The location of the output data can be changed by editing PONT_STAT_OUTPUT_DIR. The output files are labeled as point_stat_HHMMSSL_YYYYMMDD_HHMMSSV.stat. Here, HHMMSSL is the lead time and will always be 000000. HHMMSSV is the valid hour, minute, and seconds. Each file contains the following output statistics line types, listed in the LINE_TYPE column. Information on output from PointStat can be found in the MET documentation. Additionally, a description of the statistics contained in each of these lines can be found in the MET documentation and linked with each line type below

- MPR: contains matched pairs of the forecast and observation values at each station
- SL1L2: Scalar L1L2 partial sums
- CNT: Continuous statistics
- VL1L2: contains vector L1L2 partial sums on the wind data
- VCNT: contains vector continuous statistics on the wind data
- CTC: contains contingency table counts
- CTS: contains contingency table statistics

Output from Stat Analysis contains filtered and aggregated data. The output is located in OUTPUT_BASE/StatAnalysis/surface. Specifically, 7 files will be output

- WRF_MADIS_surface_2022072000_2022072023_all_stations_hourly_CNT.stat: Contains aggregated continuous statistics for all stations combined separated by hour of the day
- WRF_MADIS_surface_2022072000_2022072023_all_stations_hourly_VCNT.stat : Contains aggregated vector continuous statistics (for wind speed and direction) for all stations combined separated by hour of the day
- WRF_MADIS_surface_2022072000_2022072023_AllVars_FULL_MPR.stat: Contains the matched pair data for all variables for use in the bias plots
- WRF_MADIS_surface_2022072000_2022072023_separate_stations_CNT.stat: Contains aggregated continuous statistics for each station separately across the entire time period
- WRF_MADIS_surface_2022072000_2022072023_separate_stations_VCNT.stat: contains aggregated vector continuous statistics (for wind speed and direction) for each station separately across the entire time period
- WRF_MADIS_surface_2022072000_2022072023_wind_FULL_MPR.stat: Contains the matched pair wind data that will be used to create wind roses for the Front Range domain
- WRF_MADIS_surface_2022072000_2022072023_wind_FULL_MPR.stat: Contains the matched pair wind data that will be used to create wind roses for the Full domain

Several plots are also output to the directory OUTPUT_BASE/plots/surface. The plotting output contains images of ME, MAE, and RMSE stratified by hour of the day for temperature, dew point, relative humidity, and surface pressure. These plots are created for 2 domains, the Front Range and the full model domain. Wind roses are also output for the model, observations and their difference. The following plots are created:

- DPT_Front_Range_MAE.png: Dew Point MAE for the Front Range domain
- DPT_Front_Range_ME.png: Dew Point ME for the Front Range domain
- DPT_Front_Range_RMSE.png: Dew point RMSE for the Front Range domain
- DPT_FULL_MAE.png: Dew Point MAE for the full domain
- DPT_FULL_ME.png: Dew Point ME for the full domain
- DPT_FULL_RMSE.png: Dew Point RMSE for the full domain
- PSFC_Front_Range_MAE.png: Surface Pressure MAE for the Front Range domain
- PSFC_Front_Range_ME.png: Surface Pressure ME for the Front Range domain
- PSFC_Front_Range_RMSE.png: Surface Pressure RMSE for the Front Range domain
- PSFC_FULL_MAE.png: Surface Pressure MAE for the full domain
- PSFC_FULL_ME.png: Surface Pressure ME for the full domain

- PSFC_FULL_RMSE.png: Surface Pressure RMSE for the full domain
- RH_Front_Range_MAE.png: Relative Humidity MAE for the Front Range domain
- RH_Front_Range_ME.png: Relative Humidity ME for the Front Range domain
- RH_Front_Range_RMSE.png: Relative Humidity RMSE for the Front Range domain
- RH_FULL_MAE.png: Relative Humidity MAE for the full domain
- RH_FULL_ME.png: Relative Humidity ME for the full domain
- RH_FULL_RMSE.png: Relative Humidity RMSE for the full domain
- T2_Front_Range_MAE.png: Temperature MAE for the Front Range domain
- T2_Front_Range_ME.png: Temperature ME for the Front Range domain
- T2_Front_Range_RMSE.png: Temperature RMSE for the Front Range domain
- T2_FULL_MAE.png: Temperature MAE for the full domain
- T2_FULL_ME.png: Temperature ME for the full domain
- T2_FULL_RMSE.png: Temperature RMSE for the full domain
- wind_rose_Front_Range_diff.png: Difference wind rose for the Front Range domain
- wind_rose_Front_Range_fcst.png: WRF model wind rose for the Front Range domain
- wind_rose_Front_Range_obs.png: MADIS wind rose for the Front Range domain
- wind_rose_FULL_diff.png: Difference wind rose for the full domain
- wind_rose_FULL_fcst.png: WRF model wind rose for the full domain
- wind_rose_FULL_obs.png: MADIS wind rose for the full domain

PointStat_fcstWRF_obsSURFRAD_radiation.conf

- Computes statistics for surface radiation compared to the SURFRAD Table Mesa station. Unlike the WRF vs MADIS statistics configuration, this does not use masking regions since the observations are a single point of data
- Runs the conversion of the observation data once for each day on 07/20/2022
- Runs statistics at hourly intervals starting on 07/20/2022 at 00 UTC and ending at 07/20/2022 23 UTC

To run these statistics:

1. Change VALID_BEG and VALID_END to the start and end time of the data you want to verify and have available
2. The prefix of WRF output files is by default set to “wrfout_d03” in FCST_POINT_STAT_INPUT_TEMPLATE variable. Please change this if you have a different prefix for your WRF output data.
3. Change the times listed in the yaml plotting configuration files, custom_line_MAE_env.yaml, custom_line_ME_env.yaml, and

custom_line_RMSE_env.yaml (*if you did not already change them when running PointStat_fcstWRF_obsMADIS_surface_pe.conf*)
    a. These dates should be set to the first day of the time period that you are verifying
    b. You can change the title and output plot name by editing the title and plot_filename variables inside these yaml files
4. Make sure the input and output directories point to your input and output data. FCST_POINT_STAT_INPUT_DIR should point to the location of the model data. Need information from George about how the automatic data download will work before describing the observation info
5. Run the verification and plots by executing the following command: *run_metplus.py PointStat_fcstWRF_obsSURFRAD_radiation.conf system.conf*

Output:

Output files from Point-Stat contain the statistics for each day and time the data has run. They can be found in the directory OUTPUT_BASE/PointStat/radiation/YYYYMMDD. The location of the output data can be changed by editing PONT_STAT_OUTPUT_DIR. The output files are labeled as point_stat_HHMMSSL_YYYYMMDD_HHMMSSV.stat. Here, HHMMSSL is the lead time and will always be 000000. HHMMSSV is the valid hour, minute, and seconds. Each file contains the following output statistics line types, listed in the LINE_TYPE column. Information on output from PointStat can be found in the MET documentation. Additionally, a description of the statistics contained in each of these lines can be found in the MET documentation and linked with each line type below

- MPR: contains matched pairs of the forecast and observation values at each station
- SL1L2: Scalar L1L2 partial sums
- CNT: Continuous statistics

Output from Stat Analysis contains filtered and aggregated data. The output is located in OUTPUT_BASE/StatAnalysis/radiation. Specifically, 1 file will be output

WRF_SURFRAD_radiation_hourly_CNT.stat: Contains aggregated continuous statistics for the Boulder station combined separated by hour of the day

Several plots are also output to the directory OUTPUT_BASE/plots/radiation. The plotting output contains images of ME, MAE, and RMSE stratified by hour of the day for downwelling shortwave, new shortwave, upwelling shortwave, downwelling clear sky shortwave, upwelling longwave, and downwelling longwave. Since there is only

one observation point across the state, multiple domains would yield the same results, so only one domain is plotted. The following plots are created:

- GSW_FULL_MAE.png: Net Shortwave MAE
- GSW_FULL_ME.png: Net Shortwave ME
- GSW_FULL_RMSE.png: Net Shortwave RMSE
- LWDNB_FULL_MAE.png: Downwelling Longwave MAE
- LWDNB_FULL_ME.png: Downwelling Longwave ME
- LWDNB_FULL_RMSE.png: Downwelling Longwave RMSE
- LWUPB_FULL_MAE.png: Upwelling Longwave MAE
- LWUPB_FULL_ME.png: Upwelling Longwave ME
- LWUPB_FULL_RMSE.png: Upwelling Longwave RMSE
- SWDNBC_FULL_MAE.png: Downwelling Clear Sky Shortwave MAE
- SWDNBC_FULL_ME.png: Downwelling Clear Sky Shortwave ME
- SWDNBC_FULL_RMSE.png: Downwelling Clear Sky Shortwave RMSE
- SWDNB_FULL_MAE.png: Downwelling Shortwave MAE
- SWDNB_FULL_ME.png: Downwelling Shortwave ME
- SWDNB_FULL_RMSE.png: Downwelling Shortwave RMSE
- SWUPB_FULL_MAE.png: Upwelling Shortwave MAE
- SWUPB_FULL_ME.png: Upwelling Shortwave ME
- SWUPB_FULL_RMSE.png: Upwelling Shortwave RMSE

PlotPointObs_fcstWRF_obsMADIS_surface.conf

- Creates contour plots showing the model values with the observation points overlayed. It also runs a pre-processing step needed to create these contour plots. These graphics are only run on the surface variables compared to MADIS, since the SURFRAD data only has one point over the entire state of Colorado.

- Run this configuration after running PointStat_fcstWRF_obsMADIS_surface_pe.conf so that the observations are downloaded and available. Attempting to run this first will result in failures due to missing observations

To run these graphics:

1. Change the VALID_BEG and VALID_END to the start and end times over which you want to create plots
2. The prefix of WRF output files is by default set to “d03”. Please change the WRF_DOMAIN variable if you have a different prefix for your WRF output data.
3. If desired, you can change the minimum and maximum values of the plotted data, you will need to edit

PLOT_POINT_OBS_GRID_DATA_GRID_PLOT_INFO_PLOT_MIN, PLOT_POINT_OBS_GRID_DATA_GRID_PLOT_INFO_PLOT_MAX, plot_min, and plot_max. The first two are the minimun and maximum of the gridded data and the second two are the minimum and maximum of the point observation data. These variables appear several times in the file, once for each plot. The values for temperature are a few lines down from the [TMP] heading. For relative humidity, they are under the [RH] heading, dew point is under [DPT], and surface pressure is under [PSFC].

4. The color tables can be changed in the PLOT_POINT_OBS_GRID_DATA_GRID_PLOT_INFO_COLOR_TABLE and color_table variables respectively. The first changes the color table for the model data and the second changes the color table for the observation data.
5. Create the plots by running run_metplus.py PlotPointObs_fcstWRF_obsMADIS_surface.conf system.conf

Output:

Output plots can be found in the location specified as OUTPUT_BASE/plots/raw data. The location of the output data can be changed by editing PONT_STAT_OUTPUT_DIR. The files are labeled as WRF_MADIS_VARIABLE_YYYYMMDD_HHMMSS.ps, where VARIABLE will be either Temperature, DewPointTemperature, RelativeHumidity, or SurfacePressure

Description of the Additional Directories and Files needed:

- Both of these directories need to be available and stored in the location specified by CONF_DIR in the system.conf file

Python_scripts directory

- This directory contains python scripts used as part of the processing. These scripts should not need to be modified
- The first two scripts are needed to compute desired variables that were not present in the model and observation datasets
- The second three files handle plotting

Listing of Python scripts:

- convert_madis_sfc_allvars.py: This script is needed to calculate observed relative humidity from temperature and dew point, to convert the U and V components of wind from the wind speed and direction, and to derive surface pressure. The script would only need to be changed if the names of the MADIS observation data change

- convert_wrf_sfc.py: This script is needed because the WRF model only contains specific humidity as a moisture variable. It converts specific humidity to relative humidity and dew point to verify against the observation moisture variables. The script would only need to be changed if the names of the WRF model variables change.
- plot_bias_stations.py: This script handles plotting of the bias (ME) over a map projection for each point's location
- plot_line_stats.py: This script handles plotting of the line statistics ME, MAE, and RMSE.
- plot_wind_rose.py: This script handles plotting of the wind roses for wind data.
- reformat_CNT_linetype.py: This script handles reformatting of the output from Stat-Analysis. It is run to put the data into the format needed for METplotpy graphics.

yaml_configurations directory

- This directory contains yaml configuration files that control the reformatting and certain plot settings. Two of the files, reformat_CNT.yaml and reformat_VCNT.yaml will not need to be edited. The configuration options used in these files are specified in the [user_env_vars] section of the configuration files, PointStat_fcstWRF_obsMADIS_surfaceStatistics_pe.conf and PointStat_fcstWRF_obsSURFRAD_radiation.conf.

- The plotting yaml configuration files would only need to be edited if it is desired to change the plot colors, line thickness, or axis ranges. All other plot settings appear in the [user_env_vars] section of the two configuration files mentioned above.

Reformatting Configuration Files

- reformat_CNT.yaml: yaml settings to reformat the continuous statistics output from Stat-Analysis
- reformat_VCNT.yaml: yaml settings to reformat the wind vector continuous statistics output from Stat-Analysis

Plotting Configuration Files

- custom_line_MAE_env.yaml: Contains the settings needed for creating line plots of MAE versus hour of the day
- custom_line_ME_env.yaml: Contains the settings needed for creating line plots of ME versus hour of the day
- custom_line_RMSE_env.yaml
- Wind_rose_diff.yaml: Contains the settings needed to create the difference wind rose plots

- wind_rose_fcst.yaml: Contains the settings needed to create the model wind rose plots
- wind_rose_obs.yaml: Contains the settings needed to create the observation wind rose plots