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Development of EPW Input Files for Energy Modeling of Future Climate Change

Introduction

This white paper outlines the method by which EPW format weather files representing future climate for Portland and Bend Oregon were developed for use with energy modeling for the 2018 Energy Trust of Oregon Net Zero Fellowship project. EPW files representing historical climate are available from observations conducted at the Portland International Airport (PDX) and the Redmond Municipal Airport (RDM) near Bend.

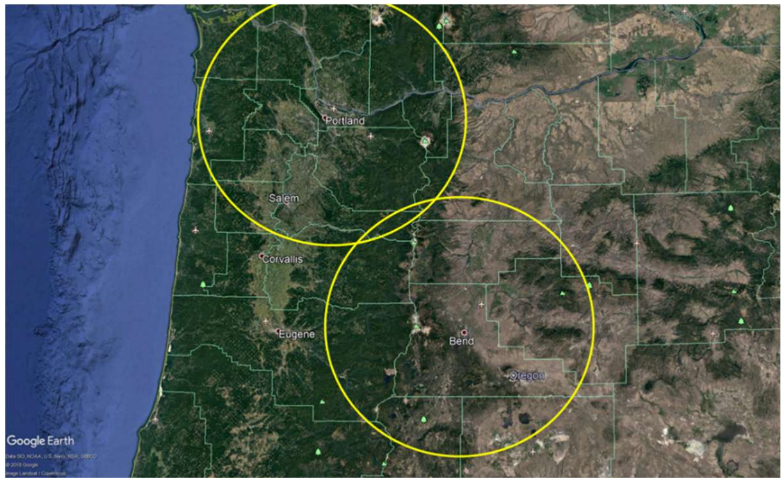
Data Requirements for TMY3 and EPW Data

To be useful for determining a typical meteorological year (TMY) and providing data for an EPW file that represents future conditions, the data source must:

- Represent weather changes related to future climate changes.
- Cover a sufficient length of time to allow calculation of a TMY (at least 10 years).
- Provide atmospheric parameters required for a TMY calculation and/or an EPW input file
- Have sufficient temporal and spatial resolution to be representative of diurnal patterns and local-scale terrain induced influences on meteorology.

Data from general circulation model (GCM) simulations of future climate are available from multiple sources and the predictions are available for periods spanning from the present to the year 2100. However, raw GCM outputs are typically only available at coarse spatial resolutions of around 1 degree or greater (about 100km/60mi in the middle latitude). At this scale the entire Portland area including both The PDX and RDM airport might lie within the same grid cell. Local influence such as land use, land water boundaries or terrain elevation are not sufficient resolved at that scale. Further, GCM are typically only available over temporal intervals of every 6 hours or greater. That is not sufficient to resolve the diurnal cycle at a given location. And lastly GCM data that are publicly available typically do not contain all the parameters that would be needed for an EPW file. Therefore, unaltered GCM data are not suitable for this exercise. Greater spatial and temporal resolution of the atmospheric parameters of interest is required. Greater spatial and temporal resolution of the atmospheric parameters of interest is required.

Figure 1: Portland & Bend OR w/ 100 km (60 mi) Radius Highlighted (source: Google Earth)



DATA SOURCE FOR FUTURE CLIMATE PREDICTIONS

To address the requirements listed above, the project used high resolution regional climate predictions from the National Center for Atmospheric Research (NCAR) to provide an estimate of the future weather in Portland and Bend.

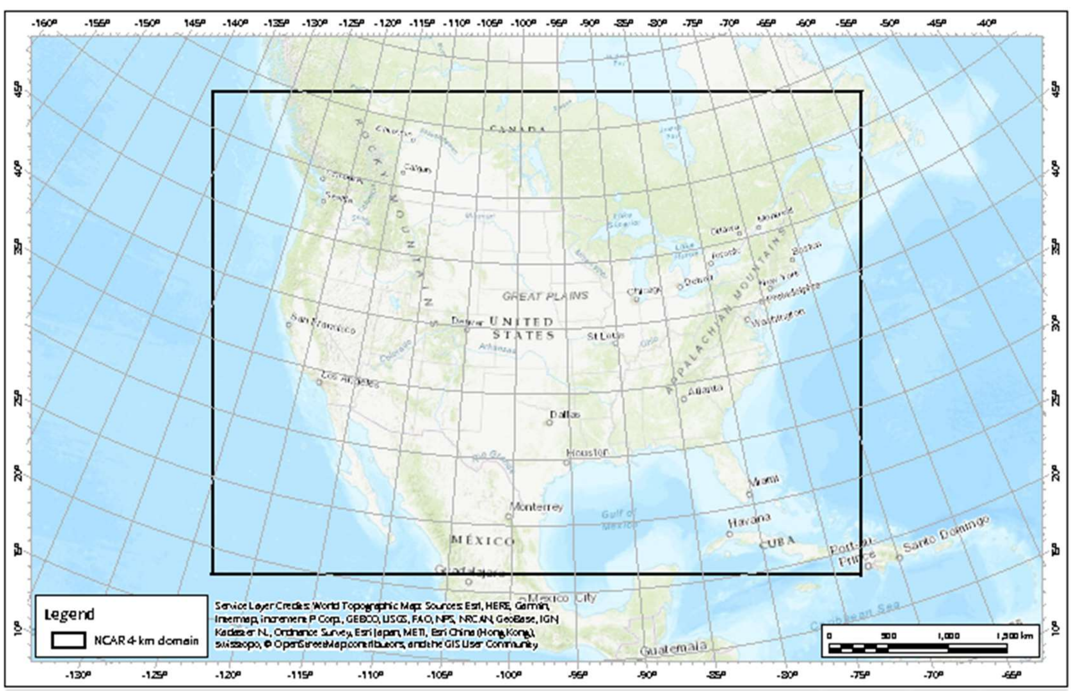
The NCAR regional climate model is based on a retrospective historical simulation of past weather using Weather Research and Forecasting Model (WRF). The WRF model (https://www.mmm.ucar.edu/weather-research-and-forecasting-model) is a numerical weather prediction system designed for both atmospheric research and operational forecasting applications. It is used by numerous agencies worldwide for multiple applications including daily weather forecasting, hurricane prediction, historical weather analysis and regional climate prediction.

WRF is a ‘mesoscale or ‘limited area model’, which means that it covers a portion (i.e. a limited area) of the globe rather than the whole globe. Because A WRF the model simulation covers only portion of the globe, it must be driven on its boundaries by data representing the larger global atmospheric condition. This boundary condition can be derived from historical global weather analyses, or it can be from data that represent a possible future weather condition. The NCAR modeling was done using WRF to do a regional climate simulation for a historical period and a future climate sensitivity of the same period based on the ensemble average of the results from CMIP5 global circulation model (GCM) experiment.

Figure 2: Illustration of WRF Limited Area Model (LAM) domain versus global domain

The NCAR climate model is based on a historical simulation of the period from 2000-2013 that provides hourly snapshots of the state of the atmosphere - including wind, temperature, precipitation and radiation balance – at 4 km (2.5 mi) resolution over all of the continental United States and much of Canada and Mexico. The NCAR domain is shown in Figure 3.

Figure 3: NCAR WRF Regional Climate Simulation Domain



A 'pseudo' or 'implied' future regional climate prediction is then developed from the same model period, but with the model adjusted or 'perturbed' by an increment calculated from explicit predictions of global circulation models (GCMs). This perturbation applied is equivalent to the ensemble average from CMIP5 the (Coupled Model Intercomparison Project Phase 5) future climate GCM results for the rcp8.5 or 'high emissions' scenario over the 2071-2100 future period. In simpler terms, the model represents the estimated effect of the worst-case climate scenario for year 2100 over the continental US.

This approach, termed a 'pseudo-global warming' regional climate model, allows for higher temporal and spatial resolution of model predictions than is available from explicit future runs of GCMs. This means that it allows for some important meteorological phenomena, such as cloud formation, precipitation and terrain induced winds, to be explicitly resolved by the model physics rather that estimated through bulk parameterizations as they typically are in GCMs, thus providing a more accurate estimation of meteorology at any given location.

For the historical or 'control' period, the large-scale boundary conditions provided to the limited area WRF run were provided from data from the ERA-Interim reanalysis project. The ERA-Interim was developed by the European Centre for Medium-Range Weather Forecasts (ECMWF). It provides historical snapshots of global weather every 6 hours from 1979 to 2019. The ERA-Interim from 2000-2013 were used to drive the historical WRF simulation.

https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim

For the future or pseudo-global warming scenario (PGW), the ERA-interim inputs were perturbed to represent the rcp8.5 emission pathway as described above, and the model was re-run over the full 13-year period.

Both the control and PGW scenario model results are provided on an hourly time interval, compared to most GCM or re-analysis outputs which typically available on a three- or six-hour time interval. The hourly interval means no interpolation is required to use the NCAR WRF results as a source for the subsequent TMY or EPW applications.

The NCAR model runs are available for download without cost and there are no restrictions for commercial use. The data are available from the NCAR Research Data Archive. https://rda.ucar.edu/datasets/ds612.0/

The modeling approach is described in more detail in the following reference.

Rasmussen, R., and C. Liu. 2017. High Resolution WRF Simulations of the Current and Future Climate of North America. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D6V40SXP

Calculation of a Typical Meteorological Year

A typical meteorological year (TMY) was calculated from the 13-years record available in the NCAR WRF for the PDX and RDM locations.

The TMY determination was done using the TMY3 methodology as outlined here.
https://www.nrel.gov/docs/fy08osti/43156.pdf

Hourly time series of meteorological variables relevant to calculating a TMY typical meteorological year were extracted from the 13-year NCAR record. For each of the PDX and RDM sites, WRF data were taken from the nearest 4-km WRF grid point to the given location. The variable used for the TMY calculation are:

- Dry-bulb temperature
- Dew-point temperature
- Wind speed
- Global Radiation
- Direct Radiation

Dry-bulb temperature, wind speed and global radiation are directly available from the WRF NCAR data. Dew-pointe temperature was calculated from hourly temperature, surface pressure and water vapor mixing ratio.

Direct Radiation was calculated from the WRF modeled incoming solar radiation using the Reindl algorithm. (https://plantpredict.com/algorithm/irradiance-radiation/)

Once the hourly variables are calculated there are 4 basic steps to creating the TMY.

1. Selection of the best 5 candidate months using a weighted Finkelstein-Schafer (FS) method
2. Ranking of the 5 months with respect to their closeness to the long-term mean and median
3. Persistence criteria are applied regarding heat waves and global radiation to exclude some of the months. The highest ranked month from step 2 that meets persistence criteria is used in the TMY
4. Concatenate the 12 selected months and smooth for 6 hours on each side of the break.

There were two deviations from the steps above. First, there was no examinations of persistence as noted in Step 3. In each case, the selection simply used the month with the highest score. Secondly, there was no smoothing applied as noted in Step 4. The reason for each was that it was unclear from the TMY3 how each step was to be performed. Thus, in the absence of a clear guidance, only the monthly scores were used to assemble the YMY.

Mapping WRF to EPW

Once a TMY was determined, the final step was to map the atmospheric and radiation parameters in the NCAR WRF data to those required in an EPW file. This was done using the EPW variable definitions and explanation provided here https://bigladdersoftware.com/epx/docs/8-5/auxiliary-programs/energyplus-weather-file-epw-data-dictionary.html#energyplus-weather-file-epw-data-dictionary

Note that not all the variables that are included in an EPW are directly available from the NCAR WRF. Variables that are not currently used in the EPW calculation, such as luminosity, were not mapped from WRF and were left missing.

Some variables in the EPW depend on actual historical observations recorded by a human observer. One example is the 'present weather code'. Obviously, this is not available for a future simulation. Where possible a weather code was re-constructed from the available data. For example, if the data showed precipitation occurred in a given hour, then that that hour was assigned a present weather code of 'rain'.

In some cases, a variable needed for the EPW can be substituted or inferred from another column in the file. For example, cloud cover is included in the EPW but is not available in the NCAR WRF. But the cloud cover is used in the EPW calculations as a proxy to calculate increased trapping of infra-red (IR) radiation from cloud, and longwave (IR) radiation is directly available from WRF, so cloud cover was left missing and the EPW files were given the direct estimate of IR radiation in its stead.

Finally, the header information in the EPW was taken from the existing EPW files available for PDX and RDM and left unchanged in the future files.

The complete mapping of each variable in the EPW files is given in Table 1 below.

Table 1: Listing of WRF to EPW Variable Mapping

EPW	WRF
Dry Bulb Temperature	2-meter temperature
Dew Point Temperature	Calculated from 2-meter temp, vapor mixing ratio and pressure
Relative Humidity	Calculated from 2-meter temp, vapor mixing ratio and pressure
Atmospheric Station Pressure	Surface Pressure
Extraterrestrial Horizontal Radiation	Calculated from day of year
Extraterrestrial Direct Normal Radiation	Calculated from day of year and latitude
Horizontal Infrared Radiation from Sky	Downward Longwave radiation at the surface
Global Horizontal Radiation	Downward Shortwave radiation at the surface
Direct Normal Radiation	Calculated using Reindl formula
Diffuse Normal Radiation	Calculated using Reindl formula
Global Horizonal Illuminance	Not currently used and not in WRF – left missing
Direct Normal Illuminance	Not currently used and not in WRF – left missing
Direct Normal Illuminance	Not currently used and not in WRF – left missing
Diffuse Horizontal Illuminance	Not currently used and not in WRF – left missing
Zenith Luminance	Not currently used and not in WRF – left missing

Wind Direction	Calculated from WRF 10-meter vector wind components
Wind Speed	Calculated from WRF 10-meter vector wind components
Total Sky Cover	Not in WRF - left missing
Opaque Sky Cover	Not in WRF - only used if IR rad not present– left missing
Visibility	Not currently used and not in WRF - left missing
Ceiling Height	Not currently used and not in WRF - left missing
Present Weather Observation	Reconstructed from WRF outputs where possible
Present Weather Codes	Reconstructed from WRF outputs where possible
Precipitable Water	Not currently used and not in WRF – left missing
Aerosol Optical Depth	Not currently used and not in WRF – left missing
Snow Depth	WRF snow depth liquid equivalent w/ snow density = .25
Days since last snowfall	Not currently used and not in WRF - left missing
Albedo	Not currently – left missing
Liquid Precipitation Depth	WRF Hourly Rainfall
Liquid Precipitation Interval	Not currently used, but equal to 1 hr for hourly data

Disclaimer

The future EPW files were developed for the specific purpose of conducting building energy modeling for the 2018 Energy Trust of Oregon Net Zero Fellowship project. This focus was integral to the methodology that was developed to create the future EPW files. As noted above not all the variables provided in a standard EPW were reproducible from the NCAR WRF climate prediction, and decision and priority were placed on providing the specific parameters required for energy modeling. Use of these files for purposes other than those presented in this study must be undertaken with caution and is done at the risk of the user.

Acknowledgements

This research has been supported by an Energy Trust of Oregon, Inc. Net Zero Fellowship grant. Any inquiries on the contents of this white paper may be directed to the co-authors (joel.good@rwdi.com and jeff.lundgren@rwdi.com).