Program for Climate, Ecosystem and Fire Applications

500 Years of Weather Scenarios for FPA

Project Report

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Foreword

In November 2000 an Assistance Agreement 1422RAA000002 was established between the Bureau of Land Management National Office of Fire and Aviation and the Desert Research Institute (DRI). One of the primary Task Orders begun under this agreement was Task Order 17 (RAF04-002) – RAWS Data Quality Check and Estimation. The DRI program for Climate, Ecosystem and Fire Applications (CEFA) has been responsible for the work done in this Task Order. This report describes the results of a modification of the Task Order to produce weather scenarios to be used by FPA for fire planning. For further information regarding this report or the project described, please contact either:

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EXECUTIVE SUMMARY

The objective of this project was to develop a 500-year run of daily weather scenarios for the Fire Program Analysis system (FPA). Weather scenarios provide physical based projections of fire-weather for the next two decades (2010-2029). The 2010-2029 period incorporates a projected warming trend over most of the U.S., but ends prior to the mid-century where significant climate changes are expected. The set of weather scenarios, or probabilistic weather observations, yields a probability distribution of fire weather on two decadal intervals (2010-2019, 2020-2029) for a given day, month or season as needed by FPA to identify cost effective fire management strategies. This work builds on a current task to develop an archive of spatially and temporally complete gridded dataset of surface weather data over North America covering the period 1979-present for use in fire planning and management.

Five hundred years (25 x 20 year periods) of daily weather scenarios covering the continental US and Alaska were created at an 8-km horizontal resolution. Output was provided in the fw9 format for fire weather software (e.g., Fire FamilyPlus (FF+)).

1. Introduction

The objective of this project was to develop a 500-year run of daily weather scenarios for the Fire Program Analysis system (FPA). Weather scenarios provide physical based projections of fire-weather for the next two decades (2010-2029). The 2010-2029 period incorporates a projected warming trend over most of the U.S., but ends prior to the mid-century where significant climate changes are expected. The set of weather scenarios, or probabilistic weather observations, yields a probability distribution of daily fire weather on two decadal intervals (2010-2019, 2020-2029) for a given day, month or season as needed by FPA to identify cost effective fire management strategies.

This work builds on a current task to develop an archive of spatially and temporally complete gridded dataset of surface weather data over North America covering the period 1979-present for use in fire planning and management. The National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR) dataset, providing high temporal (3-hourly) and spatial (32-km) resolution, is being used in this analysis. NARR data infills gaps in the observation network by providing dynamically consistent data where Remote Automated Weather Station (RAWS) and other observations are not available. Initial analysis shows that NARR does a satisfactory job in capturing observed surface variables (e.g., temperature, humidity) while reasonably capturing other surface variables (winds and precipitation), though more detailed validation analysis is being undertaken. However, NARR cannot be used by itself in creating weather scenarios, especially in capturing future conditions. For this, global climate models (GCMs) can be used to capture these features and incorporate uncertainty.

GCMs are coupled interactive ocean-atmosphere models that simulate the global climate system in three dimensions and in time. These models are dynamically driven, and are capable of simulating both externally forced changes (e.g., response to increased atmospheric levels of greenhouse gases) and internally forced modes (e.g., El Niño). Moreover, GCMs can realistically produce both weather (daily) and climate (monthly to decadal) similar to those observed. Over 20 GCMs were incorporated in creating climate scenarios for the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report. Unfortunately, GCMs are of much too coarse horizontal resolution (2 degree horizontal resolution) to be directly useful in generating weather scenarios. Furthermore daily "weather" output taken directly from GCMs is not typical available for the early 21st century, and even daily "weather" output covering the late-20th century contains significant differences from observations. Instead of relying on model "weather", historic "weather" taken from NARR was used to dictate subseasonal variability, and GCM output was used to determine seasonal behaviour or effectively the "climate change" component.

Daily weather conditions over North America are essentially a superposition of high-frequency meteorological forcing (e.g., diurnal variability, synoptic weather systems), lower-frequency forcing (seasonal to interannual to decadal modes of variability) and trend-like behaviour (e.g., climate change). To capture these features, a more temporally extensive collection of “weather” is needed to best plan for the diversity of potential “weather scenarios” that may arise in the near future. Furthermore, for planning purposes, an ensemble of “weather scenarios” provides an improved means to assess uncertainty.

The ability to assess “weather scenarios” is currently limited by either inadequate spatial resolution in GCM datasets or insufficient temporal coverage in the NARR dataset. Although it is possible to create weather scenarios by resampling the NARR dataset, problems with multivariate spatial and autocorrelation would produce data unrealistic for geographic fire management planning. So to address these issues, the advantages of each dataset were utilized to create an extensive set of weather scenarios spanning 500 years in length. Long temporal simulations of GCMs were utilized as coarse scale drivers upon which the NARR dataset was superposed. This method adds many degrees of freedom while maintaining the dynamical spatial/temporal autocorrelations associated with observed synoptic weather to generate a realistic range of weather scenarios. That is, this method produces realistic simulated daily weather patterns across the country.

Daily NARR data was superposed on to the monthly GCM output. These results were then bias corrected using a quantile based mapping approach. Previous studies have shown that direct GCM output does a poor job in representing surface observations, and hence as a stand alone product does not provide useful information for assessing future weather scenarios. Particularly noteworthy are the large biases in GCM output of relative humidity run under a modern (late 20th century) climate scenario when compared to observed conditions. Biases in relative humidity translate, for example, into modelled ERC values being far below observed values. Prior to bias correction, climate change “shifts” were removed to preserve projected changes in the mean and variance of climate elements. Together these datasets generated a 500-year run of synthetic weather/climate datasets at 8-km resolution as requested by FPA for the use of assessing fire management scenarios through the year 2030.

This project was completed under CEFA/BLM Task Order RAF04-002 Task 17.

2. Development of Scenarios

Daily data was acquired from NARR to provide 1300 local time observations as needed for implementation in fire weather analysis. Because NARR is only provided at 3-hourly intervals, temporal interpolation was applied to estimate 1300 observations across all time zones in the continental US and Alaska from 1980 through 2007. Twenty-four hour maximum and minimum temperature and relative humidity, accumulated precipitation and precipitation duration, as well as 1300 observations of temperature, relative humidity, wind velocity and state of the weather (SOW) were generated. For every 3-hourly NARR value that had precipitation ≥ 0.01”, one-hour duration was accumulated. Therefore, a 24-hour period does not exceed 8 hours of precipitation duration. State of the weather (SOW) was given only three categories (clear=0, overcast=3 and precipitating=6), and was based upon the ratio of actual downward shortwave radiation (DSW) with the potential DSW on a clear day. The potential DSW is a function of day of year and latitude. If the ratio (i.e., actual DSW / potential DWS) was ≥ 50%, then a SOW of 0 (clear) was assigned. If it was < 50%, a SOW of 3 (overcast) was assigned. If the 3-hourly NARR precipitation amount closest to 1300 LT was ≥ 0.02”, then a SOW of 6 (rain) was assigned.

Initial analysis showed that NARR contained a substantial amount of bias in capturing observed surface variables. To this end, a set of bias correction and downscaling methods were applied to achieve an improved match between the desirable qualities of a spatially and temporally complete dataset, and the in situ conditions observed on the ground and realized in fire weather.

2.1 Downscaling: Decomposition-Interpolation-Composition Method

The horizontal resolution of NARR is 32-km, which is clearly insufficient for examining meteorological parameters in regions of complex physiographic features. Disparities between NARR and ground observations (e.g., RAWS) are problematic when trying to compare gridded output to ground conditions. To improve upon the spatial resolution of NARR we make use of the PRISM (Parameter-elevation Regressions on Independent Slopes Model) dataset. PRISM uses point measurements of precipitation and temperature and considers various physical geographic factors (topography, aspect, distance to water bodies) to create a continuous gridded dataset with 4-km horizontal resolution and monthly temporal resolution covering the continental United States.

At present PRISM is only available on monthly time scales. However, a high spatial resolution footprint of monthly data from PRISM can be effectively employed, with the high temporal resolution data from NARR used to create estimates of daily temperature, precipitation and humidity on an 8-km grid using equations 1 and 2, where the subscripts P and N refer to the PRISM and NARR datasets, respectively. Transforming the data from monthly (PRISM) to daily (NARR) requires the assumption that within a 32-km grid, the day-to-day variability is determined by NARR, but that subgrid scale values are determined via PRISM. Equation 1 is used to downscale precipitation and humidity fields, while equation 2 is used for temperature fields. For humidity fields, specific humidity values were assumed equal across the 32-km grid cell. After correcting for temperature values, subgrid-scale relative humidity was calculated. We note that this downscaling method may be unable to capture fine-scale inversions in the complex terrain regions of the West as PRISM and the surface fields of NARR both cannot fully depict such features. No fine scale information exists for wind velocity, so simple spatial interpolation was applied for this element.

$$P_R(x,y,m,d) = \left[\frac{P_N(x,y,m,d)}{\sum_{d=1}^{nd} P_N(x,y,m,d)} \right] * P_P(x,y,m) \qquad \text{Eq. 1}$$

$$T_R(x,y,m,d) = T_N^*(x,y,m,d) + T_P(x,y,m) \qquad \text{Eq. 2}$$

This downscaling revealed that NARR has substantial biases in simulating maximum and minimum temperatures and humidity. This is not entirely surprising given the 3-hrly aspect of NARR where temperatures and humidity are effectively averaged over 3-hour time blocks – therein clearly unable to capture observed daily maximum/minimums, which are typically set with much shorter timescales. The upshot is that this method removes the positive biases in minimum temperature and maximum relative humidity, and the negative biases in maximum temperature and minimum relative humidity (locally exceeding 15ºF and 30%).

2.2 Empirical cumulative distribution function bias correction

The downscaling method above proved useful in eliminating most of the temperature and precipitation biases found in NARR. However, it was deemed that the relative humidity still suffered from substantial biases. A secondary method was used to bias correct the relative humidity fields in NARR using an empirical distribution matching technique where RAWS station provide ground truth data. This method seeks to fit the data along its entire cumulative distribution, as opposed to fitting it at just certain quantiles. This method is preferred when trying to fit distributions near their tails.

Data from all available RAWS for the years 2004-2006 (900+ stations) serve as the observations, and collocated NARR pixels serve as the model datasets. The empirical cumulative distribution function (CDF) method fits the distribution of the RAWS and NARR datasets. The CDF of the modeled data is then interpolated to the empirical CDF of the observed data, therein forcing the modeled data to conform to the distribution of the observed data. The transformation is calculated on an FPU-by-FPU basis taking into consideration all RAWS that exist in each FPU. For regions not covered by an FPU, a region wide fit was assumed. The bias correction method in general results in decreases in minimum and 1300 observation time relative humidity, and increases in maximum relative humidity to match the distribution of RAWS.

These two methods in tandem result in a tremendous increase in both the horizontal resolution and accuracy of the gridded dataset compared to ground observations. One further addition was to account for discrepancies in the elevation of the 8-km grid compared to the 32-km grid for wind velocity. As wind speed generally increases away from the boundary layer, the wind shear in the lowest level of the atmosphere above the topography was calculated. This wind shear was then applied to the surface wind fields, leading to an increase in wind velocity for 8-km grids located above the elevation of the 32-km grid.

2.3 Application of GCM output

To develop future weather scenarios that account for anticipated changes in climate associated with increases in atmospheric concentrations of greenhouses gases and aerosols, GCMs were run under 21st century climate runs forced by climate change emission scenarios established by the IPCC. Output from seven GCMs used in the IPCC's AR4 were acquired from the Program for Climate Model Diagnosis and Intercomparison. Models used in the analysis are comprised of GCMs that included the following output variables: surface (2-m) temperature, surface (10-m) wind, precipitation and humidity at the lowest atmospheric level. Monthly output was acquired for the periods 1980-2000, from the 20th century coupled simulations (20C3M) and 2001-2100 for three different emission scenarios (SRES-B1, SRES-A1B and SRES-A2). Most GCMs also included multiple runs, therein increasing the sampling opportunity to 25 realizations. Weather scenarios were created for two decadal periods (2010's and 2020's). As the GCMs specified here include multiple runs, it is very feasible to create a 500-year weather scenario dataset.

By utilizing the fine-scale gridded dataset described in section 2.1 above alongside climate "perturbations" from GCMs extensive set of weather scenarios spanning 500 years in length was created. The general concept was to apply an ensemble of simulations from a set of various GCMs as coarse scale drivers (both in time and space) to the fine-scale gridded dataset to yield 25 different realizations of the 20-year period from 2010-2029. This method adds many degrees of freedom while maintaining the dynamical spatial/temporal autocorrelations associated with observed synoptic weather to generate a realistic range of weather scenarios.

By incorporating gridded weather data from improved NARR and climate change information from GCMs, a set of future weather scenarios for the early part of the 21st century (2010-2029) was produced using the following procedure:

1. Daily weather (NARR at 1300 local time (required for NFDRS) was created from the improved NARR for the period 1980-2007.

2. A 90-day low pass filter was applied to the daily weather field. This retains temporal information at longer timescales, and effectively captures the seasonal cycle. The resulting dataset included both the climatology and a low-frequency component that encapsulates low-frequency variability.

3. The 90-day high pass filter was retained as the high-frequency variability (referred to as R_W in equation 3).

4. For each individual GCM monthly model output was bias corrected using the method discussed earlier. This involved using GCM output covering the time-period 1980-2000 to match both the means and variability seen in NARR

observations for the same time-period. These bias adjustments were then applied to the time-period 2010-2029.

5. Monthly data from GCM from 2010-2029 was transformed to daily data using a spline interpolation, and the 90-day low pass filter was taken from the data. This 90-day low pass filter retains the climatology from observations as well as the low-frequency variability and anthropogenic perturbation component from the GCM (referred to as R_{GCM} in equation 3).

6. A 20-year weather scenario was formed by adding the 20-year GCM output with a 20-year data set from NARR (referred to as R_D in equation 3). A random number generator was used to determine the starting year of NARR (1980 to 1988).

$$R_D(x,y,d,yr) = R_W^{'}(x,y,d,yr) + R_{GCM}(x,y,m,yr) \qquad \text{Eq. 3}$$

The above methodology was applied for both temperature and wind speed; however, modifications were made for relative humidity and temperature. Application of the above methodology to relative humidity resulted in numerous occasions of supersaturated conditions. Instead, the linear trend of specific humidity in each model or a monthly basis was calculated and added to the climatology in place of step 5 above. Relative humidity was then computed using the temperatures calculated. Occurrences of supersaturation, less in number, were adjusted to 100%. For precipitation, linear trends of monthly precipitation were multiplied to the unaltered daily precipitation fields. Daily wind direction and state of the weather were unchanged.

3. Deliverables

Five hundred years (25 x 20 year periods) of daily weather scenarios covering the continental US and Alaska were created at an 8-km horizontal resolution. Output was provided in the fw9 format for fire weather software (e.g., Fire FamilyPlus (FF+)). The year demarcation in the files resulted in a bug when attempting to ingest into FFP; however, a modified version was developed to account for the forward-looking nature of this product. Station identifiers for Alaska and the US with their associated latitude-longitude coordinates can be found at:

http://www.wrcc.dri.edu/research/jtwrcc/CEFA/FPA/DATA/FPA_8KM_USALASKA_ID.txt
http://www.wrcc.dri.edu/research/jtwrcc/CEFA/FPA/DATA/FPA_8KM_USCONTINENTAL_ID.txt

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