9.2 A MODEL TO PREDICT RED FLAG WARNING DAYS

Randall P. Benson*
South Dakota School of Mines & Technology, Rapid City, South Dakota

Greg Carbin
NOAA Storm Prediction Center, Norman, Oklahoma

1. INTRODUCTION

The Red Flag program is a means by which the weather forecaster informs the land management agencies of the combination of dry fuels and critical weather conditions that support extreme fire behavior. A Red Flag Warning is used to warn of impending critical weather conditions that could result in extensive wildland fire activity. A warning is typically issued when the forecast time of onset of such conditions is less than 24 hours. Warnings are issued when Red Flag Warning meteorological criteria combine with sufficiently dry wildland fuel conditions. Thresholds for both critical weather and fuels conditions are defined in the Annual Operating Plan of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) forecast office.

The Map Analog Retrieval System (MARS) was developed at the Storm Prediction Center (SPC) in Norman, Oklahoma. MARS is based on the National Center for Environmental Prediction (NCEP) Global Forecasting System (GFS) ensemble mean and uses the 850mb, 500mb, and precipitable water fields as predictors from 0000 and 1200 UTC. MARS analog dates are derived from the North American Regional Reanalysis (NARR) using the predictors previously mentioned.

The Red Flag weather criteria used to issue Red Flag Warnings for the Rapid City county warning area consist of days in which temperatures are expected to exceed 80 degrees Fahrenheit, the wind speed exceeds 25 mph (gusts), and the minimum relative humidity is expected to fall below 15%. The likelihood of dry lightning is also an important consideration used in issuing Red Flag Warnings but this criterion is not used in determining the capability of the MARS system to predict "Red Flag weather" in this phase of the study. Dry lightning potential is expected to be included in a future analysis of the MARS prediction system.

*Corresponding author address: Dr. Randall P. Benson, IAS, SDSM&T, 501 East Saint Joseph Street, Rapid City, SD 57701; e-mail: randall.benson@sdsmt.edu

The meteorological variables relevant to affecting fire behavior result from synoptic scale forcing of weather occurring at the micro-scale where fire, weather, fuels, and topography interact. Diurnal changes in relative humidity, temperature, and wind speed and direction may dramatically influence fire behavior (Flannigan and Harrington, 1987; Hirsch and Flannigan, 1990). Lightning causes many forest fires each year when fuels are receptive. Nash and Johnson (1996) found that lightning is more efficient at starting fires under synoptic high pressure when persistent rainfall is unlikely. Atmospheric instability, normally computed daily by the Haines Index (Haines, 1988), extended dry spells, and cold front passages are other examples of weather conditions that are important to managing wildfires and maintaining safety for firefighters (Johnson and Miyanishi, 2001; Brotak and Reifsnyder, 1977) but are outside the criterion used to determine Red Flag Warning days.

2. METHODS

For the purposes of this study, the predicted red flag weather probabilities (temperature, wind speed, and relative humidity) are constructed from 0000 UTC output from each of the three MARS predictors showing the top ten analogs or matches and ranked according to the Root-Mean-Squared Error (RMSE) for each 24-hr forecast period out to ten days. Next, a computer program develops the Relative Analog Frequency (RAF) for each Red Flag weather variable and for each MARS predictor for each 24-hr forecast out to ten days. The RAF is constructed from an archived Automated Surface and Observing System (ASOS) climate dataset from 1979 to 2004 containing the Red Flag criteria for Rapid City.

The RAF is used to denote the relative frequency of MARS analogs for each MARS predictor indicating the likelihood of Red Flag weather criteria forecast to ten days. For example, if six out of ten

500 mb analogs for a MARS Day-1 forecast indicate that the temperature exceeded 80 degrees Fahrenheit, then the 500 mb RAF for the Day-1 prediction of Red Flag temperature would be 0.6.

Red Flag Warning model predictions and observations of actual weather and actual Red Flag Warning events are considered for the area of western South Dakota in the NOAA NWS Rapid City county warning area.

3. PATTERN/MAP PREDICTIONS

The first step in the verification of the MARS model to anticipate Red Flag Warning events is to determine if the model is predicting a synoptic weather pattern that is typically associated with actual Red Flag Warning events in the northern plains of the United States. For the current year, 2007, a ranked list of days of weather conditions observed at the Rapid City Regional Airport ASOS from 1 June through 31 August were used to compare to actual MARS predictions. The ASOS sorted rank was developed by considering days in which Red Flag weather conditions are met or nearly met. The top 10% of days were extracted from the 2007 ASOS observations in which near Red Flag weather conditions occurred based upon days in which the observed relative humidity fell below 15%. The average maximum temperature for these top 10% of days (11 total days) was observed to be 102 degrees Fahrenheit, well above the 80 degree Fahrenheit threshold. The average maximum sustained wind speed was 18.7 mph, which was near the 25 mph threshold. These 11 critical fire weather days were plotted and contoured on a map of the United States and compared to similar day MARS predictions (Figures 1 and 2).

Likewise, a short list of MARS Red Flag predictions was constructed from the 500 mb predictor averages of all days 1 through 10 forecasts during summer 2007 containing the predictor RAF's of minimum relative humidity less than 15%. As a result, 8 Red Flag weather days were identified, which reflect the top 10% of all the forecast minimum relative humidity predictions for days 1 through 10. Contoured maps of both the observed 2007 days and the MARS model predicted days were developed using the Climate Diagnostic Center (CDC) web page: *http://www.cdc.noaa.gov/Composites/Day/index.html.* It can be seen that overall, the pattern matches for each of four variables (500 mb height, sea level pressure, 700 mb relative humidity, and 850 mb vector wind) of observed and predicted "Red Flag Warning" days correspond quite closely by comparing Figures 1 and 2.

4. CRITICAL WEATHER PREDICTIONS

To investigate how skillfully the MARS model system was able to predict "Red Flag" relative humidity, wind speed, and temperature, the Probability of Detection (POD) and False Alarm Rate (FAR) were used (Green and Swets, 1966/1974). Each of the three MARS predictors was used in the POD and FAR calculation to see which MARS predictor actually forecast each critical observed meteorological variable the most skillfully. The MARS 500mb analog was generally the best performer when compared to the 850mb height and precipitable water MARS predictors. The MARS 500mb predictor to determine 80 degrees or greater temperatures was found to have a significantly higher POD than using the 500mb predictor to forecast critical wind speeds or daily minimum relative humidity values. Unfortunately, neither the 850mb or precipitable water predictors performed any better at predicting wind speeds or relative humidity when compared to Rapid City ASOS observations (Figure 3).

To compare the 2007 observed approximate Red Flag weather days graphically (which includes the three NOAA NWS-issued Red Flag Warning days) to the MARS model predictions for Red Flag weather, an average of the RAF's for temperature, relative humidity, and wind speed was calculated from the days 1 through 10 predictions of the MARS 500mb predictor. This average is plotted for each model run with the actual top 10% of 2007 approximate Red Flag weather days and is shown in Figure 4. Although not perfect, the observed 2007 Red Flag weather days fall within the higher RAF range of all the days of the 500 mb MARS predictions.

Three actual Red Flag Warnings were issued during the summer of 2007 by the Rapid City NWS during the June through August period for the county warning area including Rapid City. However, there were actually no days during 1 June to 31 August where all three observed Red Flag meteorological variables matched the actual Red Flag criteria.

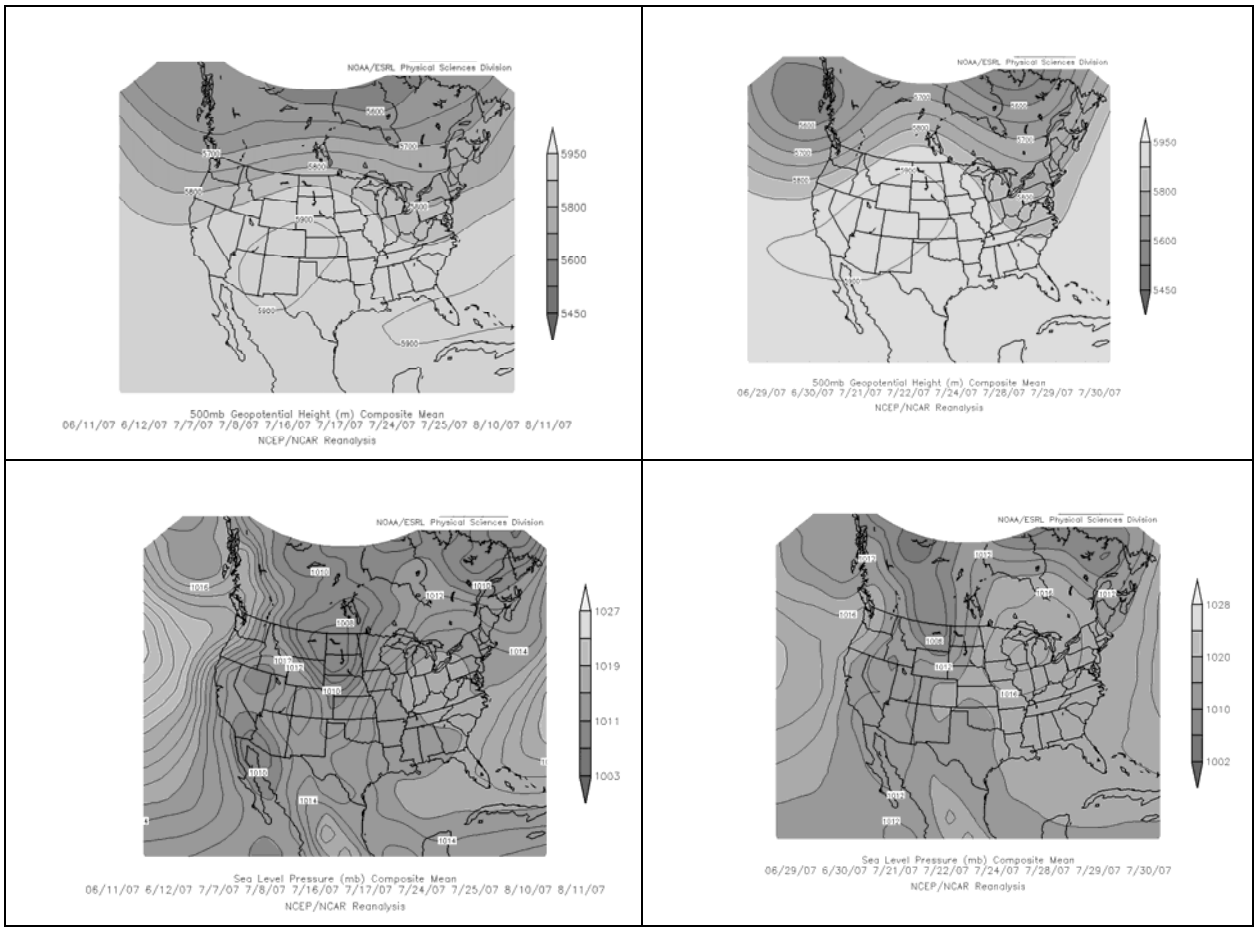

Figure 1. Top 10% of observed near Red Flag weather days (left) and MARS average 1-10 predicted days (right) of the 500 mb predictor from 1 June to 31 August, 2007 for 500 mb geopotential height and sea level pressure.

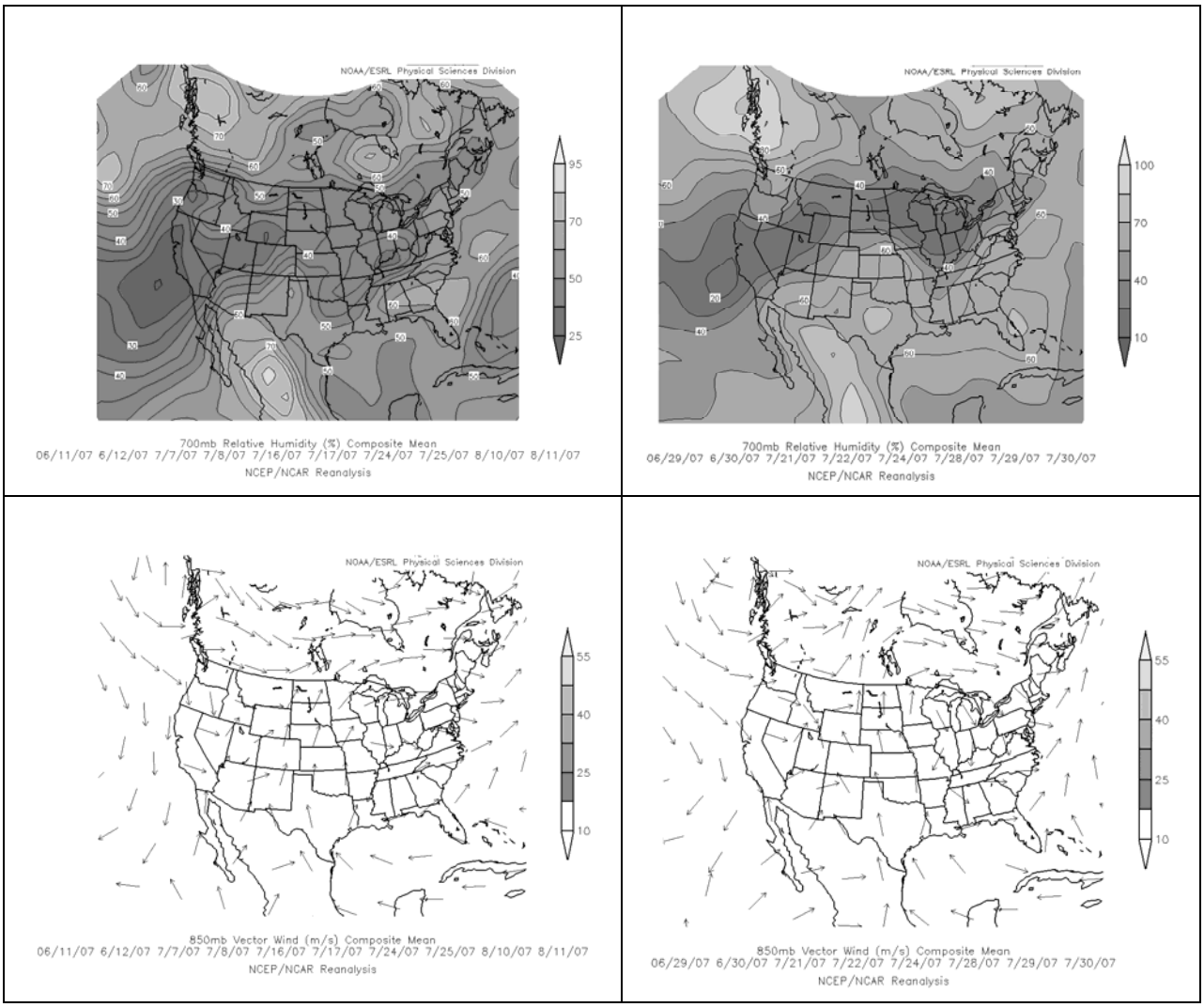

Figure 2. Top 10% of observed near Red Flag weather days (left) and MARS average 1-10 predicted days (right) of the 500 mb predictor from 1 June to 31 August, 2007 for 700 mb relative humidity and 850 mb vector wind.

Predictor	**POD T**	**POD RH**	**POD WS**
500mb Height	0.959	0.162	0.454
850mb Height	0.890	0.142	0.297
Precipitable Water	0.905	0.129	0.310
Predictor	**FAR T**	**FAR RH**	**FAR WS**
500mb Height	0.256	0.091	0.283
850mb Height	0.418	0.107	0.240
Precipitable Water	0.532	0.087	0.271

Figure 3. The Probability of Detection (POD) and False Alarm Rate (FAR) from MARS RAF's of temperature (T) exceeding 80 degrees Fahrenheit, minimum relative humidity (RH) below 15%, and wind speed (WS) gusts exceeding 25 mph.

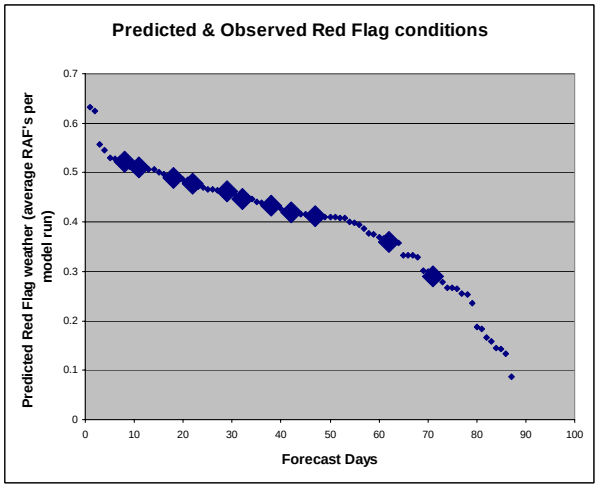

Figure 4. The MARS 500 mb predictor RAF (Relative Analog Frequency) average (small markers) for all three Red Flag weather variables for days 1 through 10 predictions is shown plotted with the actual days in which "approximate" Red Flag weather was observed at the Rapid City Regional Airport ASOS in 2007 (large markers).

5. SUMMARY AND CONCLUSIONS

Overall, the synoptic weather pattern that is associated with Red Flag Warning conditions in western South Dakota was forecast fairly well by the MARS prediction model based on a comparison of approximate observed Red Flag weather days and MARS predicted days. Overall, Red Flag conditions occur in western South Dakota with the following synoptic-scale features: a strong ridge of high pressure aloft; a dry tongue of air stretching southwest to northeast from central California to South Dakota, surface high pressure located over the Midwest and/or Ohio Valley with surface low pressure centered over western South Dakota, and near-surface westerly winds located over Wyoming and Montana.

The MARS model system detected critical Red Flag temperatures more skillfully than either wind speeds or relative humidities. The MARS 500 mb predictor was found to better predict the Red Flag weather variables more accurately than either the 850 mb or precipitable water predictors. Unfortunately, the MARS model was not able to predict either critical wind speeds or critically low relative humidity days with any skill. This may be due to a relatively short MARS analog dataset and/or to biases within the MARS model in matching the GFS ensemble means of the predictors.

Future work is anticipated to assess the capability of the MARS model to predict dry lightning events in addition to the Red Flag weather criteria and to explore the final Red Flag Warning probability including the use of a 10-day predicted Energy Release Component (ERC) value.

6. Acknowledgements

The authors would like to thank Cory Mohn, currently an Atmospheric Science graduate student, for his help in developing the Red Flag Warning Days computer program and for the MARS model output from the SPC in Norman, Oklahoma. Funding for State Fire Meteorologist Randall Benson is provided by the State of South Dakota.

7. References

Brotak, E.A. and W.E. Reifsnyder, 1977: An investigation of the synoptic situations associated with major wildland fires. *J. Appl. Meteorol*., **16**, 867-870.

Flannigan, M.D. and J.B. Harrington, 1987: Synoptic conditions during the Porter Lake burning experiment. *Climatol. Bull*., **21**, 19-40.

Green, D.M. and J.A. Swets, 1966/1974: *Signal detection theory and psychophysics* (A reprint, with correlations of the original 1966 ed.). Huntington, NY: Robert E. Krieger Publishing Co.

Haines, D.A., 1988: A lower atmosphere severity index for wildland fires. *Nat. Weath. Digest,* **13**, 23-27.

Hirsch, K.G. and M.D. Flannigan, 1990: Meteorological and fire behavior characteristics of the 1989 fire season in Manitoba, Canada. *In* "International Conference on Forest Fire Research," pp. B.06-1-B.06-16, Coimbra.

Johnson, E.A. and K. Miyanishi, 2001: *Forest Fires.* Academic Press, San Diego, California, 594 pp.

Nash, C.H. and E.A. Johnson, 1996: Synoptic climatology of lightning-caused forest fires in subalpine and boreal forests. *Can. J. For. Res*., **26**, 1859-1874.