A PILOT STUDY EXAMINING MODEL-DERIVED PRECIPITATION EFFICIENCY FOR USE IN PRECIPITATION FORECASTING IN THE EASTERN UNITED STATES

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Abstract

In 1996, the NOAA/National Weather Service (NWS) Ohio River Forecast Center (OHRFC) implemented model-derived precipitation efficiency (PE) to assist in evaluating the expected spatial and temporal distribution of precipitation. PE can be derived from any numerical weather prediction model where precipitable water (PW) for the entire atmospheric column and mean relative humidity (RH) for the 1000-700 hPa layer are computed. The goal of this paper is to describe a technique by which precipitation forecasting skills can be improved using PE.

The PE model-derived parameter has proven to be a useful tool in refining the probability, timing, duration, coverage, and intensity of precipitation. PE was shown to provide value-added information to assist the hydrometeorologist in preparing precipitation forecasts. Results using the NWS/National Centers for Environmental Prediction (NCEP) Eta model show that as the value of PE increases, the percentage of precipitation occurrences also increases. In addition, results indicate that the onset of precipitation is tied to critical PE values and temperatures.

1. Introduction

Quantitative precipitation forecasts (QPFs) have been an integral part of the river and flood forecast program in the NOAA/National Weather Service (NWS) Eastern Region since 1977 (Opitz et al. 1995) and NWS-wide since the 1990s (Fenbers et al. 1995). Forecasts of precipitation amounts and onset are critical to the achievement of the greatest possible hydrologic forecast accuracy and longest possible lead-times (Georgakakos and Hudlow 1984). As part of the NWS modernization program, a Hydrometeorological Analysis and Support (HAS) function was created at the NWS River Forecast Centers (RFCs) to maintain the QPF process. The HAS function utilizes the 6-hour national QPF guidance from the NWS/Hydrometeorological Prediction Center (HPC) and examines an array of meteorological model and mesoscale parameters in formulating the 12- and 24-hour HAS QPFs. The HAS QPF is completed twice daily around 0000 UTC and 1200 UTC and is incorporated into the NWS River Forecast System (NWSRFS) to produce river forecasts out to three to five days. In addition to addressing the spatial and temporal challenges of precipitation forecasting at RFCs, there is a continuing need to improve the Probability of Precipitation (POP) forecasts at NWS Weather Forecast Offices (WFOs). Improved methods for precipitation forecasting could benefit both NWS RFCs and WFOs. One such method is presented here.

2. Background

Precipitable water (PW) and mean relative humidity (RH) estimates have been derived using real-time satellite data at the NOAA/National Environmental Satellite, Data and Information Service (NESDIS) since the early 1980s. These parameters are then used to estimate the efficiency of precipitation processes so that adjustments to rainfall estimates can be made (Scofield 1987; Vicente et al. 1998). In 1996, the Ohio River Forecast Center (OHRFC) applied the NESDIS PW/RH method to model-derived precipitation forecasts. In order to apply a real-time technique to model-based forecasts, there was a need to use model-derived weather parameters to approximate precipitation efficiency (PE). PE is defined as the ratio of the total rainfall to the total condensation (Weisman and Klemp 1982; Ferrier et al. 1996). While the former can be derived from standard numerical models, the latter is not readily available. Therefore, an approximation is needed.

Several factors affect PE including saturation ratio, production rate of condensate, residence time of droplets in clouds, dry air entrainment, vertical wind shear, and precipitable water (Doswell et al. 1996). A prerequisite for high rainfall intensity is a large production rate of condensate. The rate at which the condensate is produced in a column of cloudy air is directly proportional to air density, updraft speed, cloud thickness, and the vertical gradient of the saturation mixing ratio. The density and vertical gradient of the saturation mixing ratio terms act to produce larger condensate rates in the lower half of the cloudy column (C. F. Chappell, personal communication, 1997). The residence time of droplets in clouds also plays a critical role in increasing PE. With increased vertical motion and increased cloud depth, cloud droplets spend more time in the cloud, growing large enough to become rain drops (C. F. Chappell, personal communication, 1997). Vertical wind shear plays a critical role since the shear often leads to dry air entrainment, reducing PE. Finally, a high PW increases PE. Typically, precipitable water values range from 1.50 inches or greater during the warm season (N. W. Junker, personal communication, 1997) to around 0.80 inches or more in the cool season.

For the operational hydrometeorologist, a simple relationship related to precipitation efficiency is defined as

$$PE = PW \; x \; RH \qquad (1)$$

where PW is the precipitable water through the entire atmospheric column and RH is the average lower-tropospheric relative humidity (Scofield 1987). PW and RH are easily obtainable from numerical weather prediction models, although the usefulness of gridded data is limited by the model from which it is derived (Scofield and Kusselson 1996). The PW/RH relationship indicates a potential efficiency of the environment for producing precipitation at specific times in the future. Thus, this model-derived PW/RH parameter is referred to as Precipitation Efficiency (PE) for the operational forecast process at NWS WFOs and RFCs. It must be emphasized that this model-derived PE is only an approximation of PE, using only PW and RH, and not actual PE as discussed earlier.

3. Data and Methodology

This section discusses ways PE can be implemented into the precipitation forecasting process, and a description of data sources and analysis techniques used. PE is calculated as follows:

$$PE = PW * (1000\text{-}700 \; MRH) \qquad (2)$$

where PE = precipitation efficiency, PW = precipitable water through the entire depth of the atmosphere (inches), and 1000-700 MRH is the mean relative humidity over the 1000-700 hPa layer, expressed as a decimal value. This layer was chosen because the deep moisture is mainly contained in the lowest 3-4 km of the atmosphere (N. W. Junker, personal communication, 1997).

Table 1. Dates used in study.

1997	March 18
March 1	March 19
September 9	March 31
September 23	April 3
October 26	April 16
November 13	May 22
November 21	June 14
December 9	June 21
December 10	June 22
	June 27
1998	June 28
January 22	June 29
January 27	
February 3	**2001**
February 4	July 28
February 5	August 25
February 18	September 7
February 23	September 8

PE can be displayed as an added volume browser customization within the Advanced Weather Interactive Processing System (AWIPS) D2D meteorological display software (Biere 1998). Readily available software such as General Meteorological Data Assimilation, Analysis and Display Software Package (GEMPAK; desJardins and Petersen 1985), NWS National Centers Translator (Ntrans), and GEMPAK Analysis and Rendering Program (GARP) are also capable of integrating PE into their list of precipitation forecasting parameters. This allows for widespread use of the PE parameter in all sectors (government, academia and private).

The authors examined twenty-seven cases from March 1997 through June 1998 (Table 1) in which precipitation occurred within the OHRFC hydrologic service area. An additional four cases occurring from July 2001 through September 2001 were examined.

In the cases for March 1997 through June 1998, PE values were taken from the NWS/National Centers for Environmental Prediction (NCEP) 50-layer, 29-km Eta numerical weather prediction model using GARP. PE values were determined for each six-hour interval of the 48-hour model forecast for six different cities in the Ohio Valley region (Table 2). Six-hour intervals were chosen due to the limits of model output intervals and resolution at the time of data collection. In addition, six-hour intervals allow the capture of model temporal and spatial uncertainty. Furthermore, occurrence of precipitation forecasts are usually made in six-hour intervals or greater. This dataset provided a total of 1296 forecast times and locations against which observed precipitation could be compared. These forecast values were compared to the monthly Local Climatological Data (LCD) hourly rainfall amounts at each location. In addition, a warm season case from 29 June 2001 and a transition season case from 9 March 2002 are shown. Using the NWS AWIPS D2D meteorological analysis software, a comparison was made between PE and the Ohio Valley regional 0.5° angle reflectivity radar mosaic to show the utility of PE.

The PE values (inches) derived from the Eta model were compared against the percentage of observed precipitation occurrences (PPO). The PPO was calculated by dividing the number of occurrences by the total number of 6-hourly intervals for each location. An occurrence is defined as when 0.01 in. of precipitation or greater was recorded at a particular location during any hour of the 6-hour interval. The 6-hour intervals were grouped into three categories to account for seasonal moisture influences driven by temperature and amount of available moisture in the atmospheric column. To do this, a mean temperature was calculated for all the 6-hour intervals

Table 2. Cities and their three-letter identifiers used in study.

Charleston, West Virginia	CRW
Cincinnati, Ohio	CVG
Columbus, Ohio	CMH
Indianapolis, Indiana	IND
Nashville, Tennessee	BNA
Pittsburgh, Pennsylvania	PIT

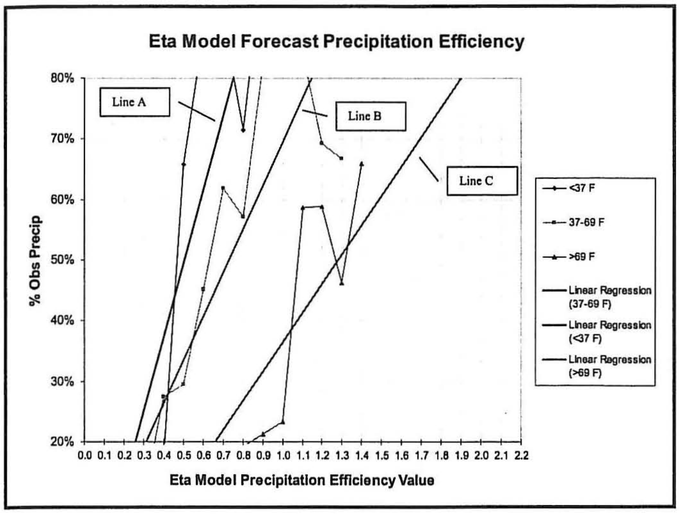

Fig. 1. Relationship between Eta model precipitation efficiency (in.) and Percentage of observed Precipitation Occurrence (PPO). Thin line with diamonds represents cool-season precipitation events (mean surface temperature < 37 °F); thin line with squares represents mean transition-season events (mean surface temperature 37-69 °F); thin line with triangles represents warm-season events (mean surface temperature > 69 °F). Lines A, B, and C represent linear regression lines for the cool-, transition-, and warm-season events, respectively.

from May 1997 to June 1998. The first category, called the mean transition season category, was defined as those 6-hour intervals with a mean surface temperature within one standard deviation of the overall mean surface temperature (54°F). The second category, called the cool season category, was defined as those 6-hour intervals with a mean surface temperature more than one standard deviation lower than the overall mean. The final category, called the warm season category, was defined as those 6-hour intervals with a mean surface temperature more than one standard deviation higher than the overall mean temperature. A linear regression line was computed for all groups (Fig.1).

4. Results

In Fig. 1, results show the plot of the three categories and their linear regression lines. Using the linear regression lines, the PE values associated with the 80 PPO for the cool, transition, and warm season categories were 0.75 in., 1.15 in., and 1.90 in., respectively. The PE values associated with the 50 PPO for the cool, transition, and warm season categories were 0.50 in., 0.75 in., and 1.30 in., respectively. The PE values associated with the 20 PPO for the cool, transition, and warm season categories were 0.25 in., 0.30 in., and 0.65 in., respectively. These differences between cool, transition, and warm season categories can be attributed to seasonal variations in moisture and the random nature of scattered afternoon convection, especially during the warm season. Correlation coefficients for the cool, transition, and warm season of 0.93, 0.92, and 0.90 respectively, provide confidence in the utility of this parameter. Based on these results, the OHRFC developed monthly precipitation efficiency thresholds (Fig. 2) and

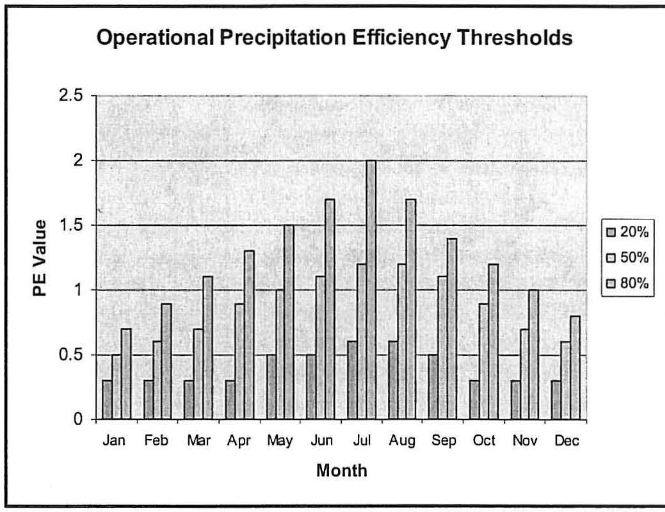

Fig. 2. Monthly precipitation efficiency (PE) thresholds (in.) for the Ohio River Valley for 20% (left), 50% (center), and 80% (right) observed precipitation occurrences.

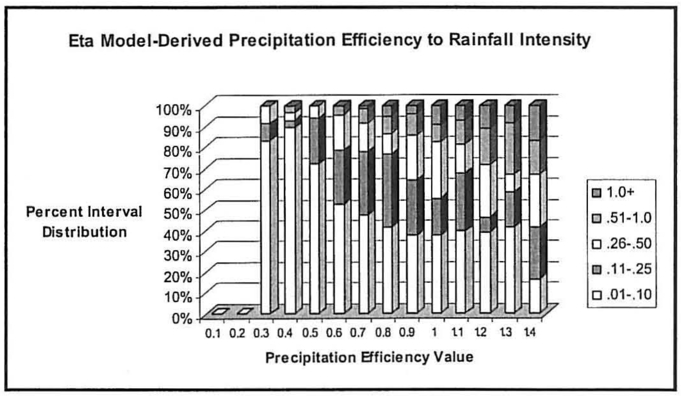

Fig. 3. Relationship between precipitation efficiency (PE, in.) and 6-hour precipitation accumulation (in.). Data taken from the period March 1997 through June 1998. Note the general trend of increased rainfall amounts with larger values of PE.

they are used by the NWS Forecast Office in Atlanta (ATL) for their area of responsibility.

PE has also shown the capability to indicate precipitation intensity. High values of PW and instability are often collocated and become antecedent conditions prior to the development of heavy rainfall and flash floods (Scofield and Kusselson 1996; Scofield et al. 2000). High values of PW can produce high values of PE if RH is high. Data from March 1997 through June 1998 show evidence that the proportion of heavier precipitation occurrences (greater than 0.25 in. over a six-hour period) to total occurrences is larger with higher PE values (Fig. 3).

In addition to providing some level of confidence in the PPO, PE has displayed the ability to detail the axis of precipitation development and movement. This is especially important when a precipitation forecast is made for input into a hydrologic model. Spatially centering the axis of precipitation is critical in projecting which locations on certain rivers will rise, recess, or remain steady. During times of high flow, such a prognosis in determining the axis of precipitation can mean the difference between issuing and not issuing a flood forecast.

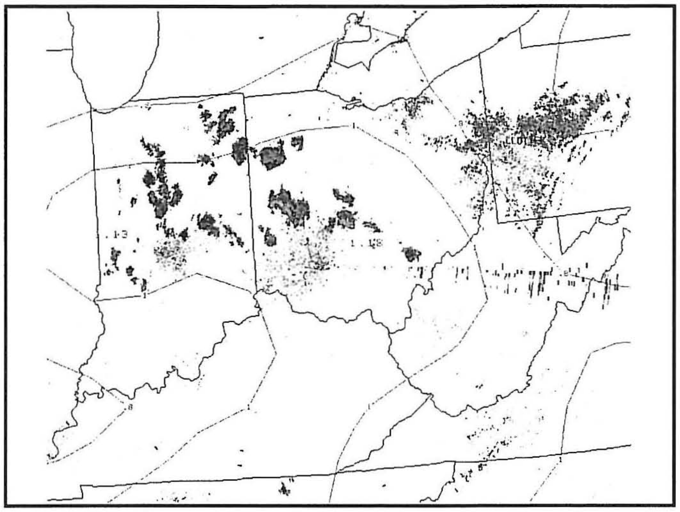

Fig. 4. 1130 UTC 29 June 2001 0.5° elevation angle radar reflectivity mosaic (dBZ) and Eta 12-h forecast of precipitation efficiency (in.) valid at 1200 UTC 29 June 2001.

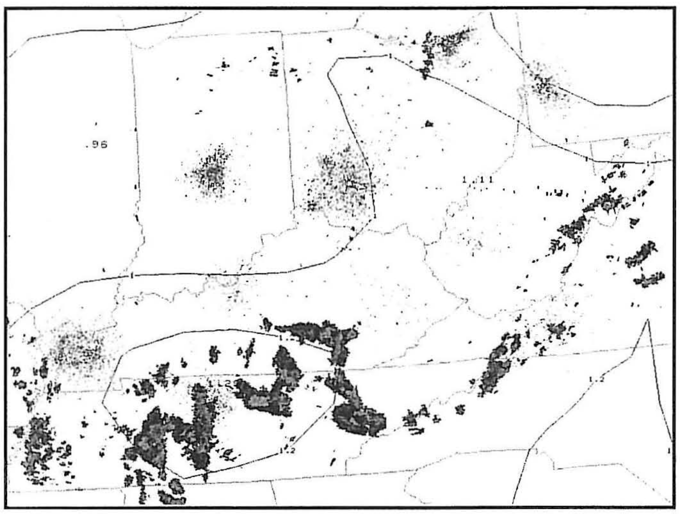

Fig. 5. 1800 UTC 29 June 2001 0.5° elevation angle radar reflectivity mosaic (dBZ) and Eta 6-h forecast of precipitation efficiency (in.) valid at 1800 UTC 29 June 2001.

Comparisons of PE to radar reflectivity during the summer of 2001 and spring of 2002 have shown the ability of PE values to highlight the axis and areal coverage of precipitation. Spring and summer cases were chosen to show PE performance in both a synoptic case (spring) and a local forcing case (summer). On 29 June 2001, scattered convection developed in an area from Indianapolis, Indiana eastward to near Dayton, Ohio during the morning hours. Evaluating the 12-h Eta model forecast of PE valid at 1200 UTC 29 June 2001 overlaid with the 1130 UTC 29 June 2001 Ohio Valley regional 0.5° angle reflectivity mosaic (Fig. 4), it is evident that PE provided a fair solution in portraying the areal coverage and axis of precipitation. In examining the 6-h Eta model forecast of PE valid at 1800 UTC 29 June 2001 overlaid with the 1800 UTC regional 0.5° angle reflectivity mosaic (Fig. 5), PE provided an indication of the shift in developing convection by the afternoon across the Cumberland River Valley. PE performance is illustrated in a third example

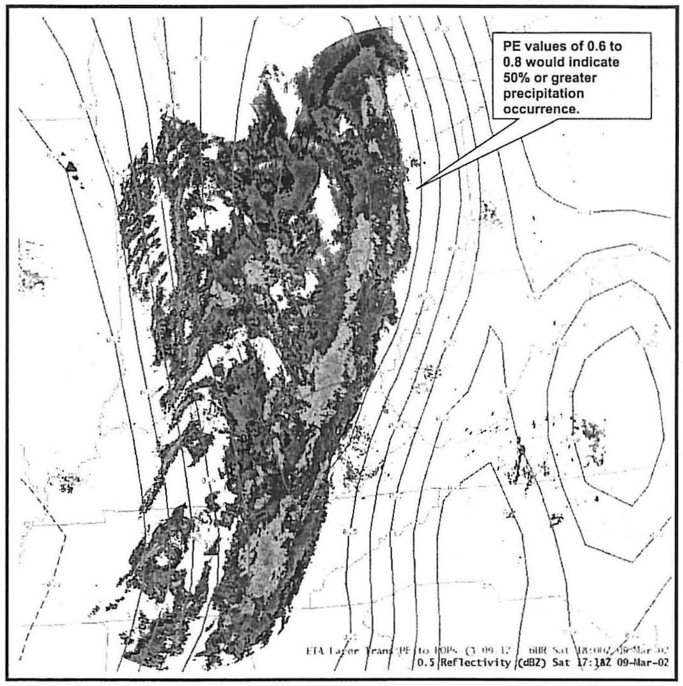

Fig. 6. 1718 UTC 9 March 2002 0.5° elevation angle radar reflectivity mosaic (dBZ) and Eta 6-h forecast of precipitation efficiency (in.) valid at 1800 UTC 9 March 2002.

in which a cold front pushed across the Ohio and Tennessee valleys on 9 March 2002. The 6-h Eta model forecast of PE valid at 1800 UTC 9 March 2002 highlighted the impending coverage and axis of precipitation when compared to the 0.5° angle reflectivity mosaic near the same time period (Fig. 6).

Finally, Fig. 7 shows how PE can be used to forecast precipitation more accurately than the individual components used to derive it. The four-panel image displays Eta model derived PW, Eta model PE, Eta model 1000-700 hPa mean RH, and an infrared (IR) satellite image for 0600 UTC 30 March 2002. The main convection was occurring across northern Mississippi, Alabama and Georgia into eastern Tennessee. PW focused on northern Mississippi and Alabama while 1000-700 hPa relative humidity focused over eastern Tennessee. When combining PW/RH together, PE focused on the area where the strong convection occurred.

5. Conclusions and Future Research

PE is not a stand-alone indicator for precipitation, but it has been proven as a very useful tool in evaluating the spatial and temporal distribution of precipitation. This parameter can assist in refining probability of precipitation forecasts. When applied alongside other traditional or useful parameters such as 950-850 hPa low-level jet convergence, 300-200 hPa upper-level jet divergence, 950-850 hPa theta-e advection, 850-500 hPa omega and other indices, PE can be a more valuable tool than relying on its foundational components individually.

Additional case studies are needed to further examine the threshold criteria for heavy rainfall during different times of the year and at different surface temperatures

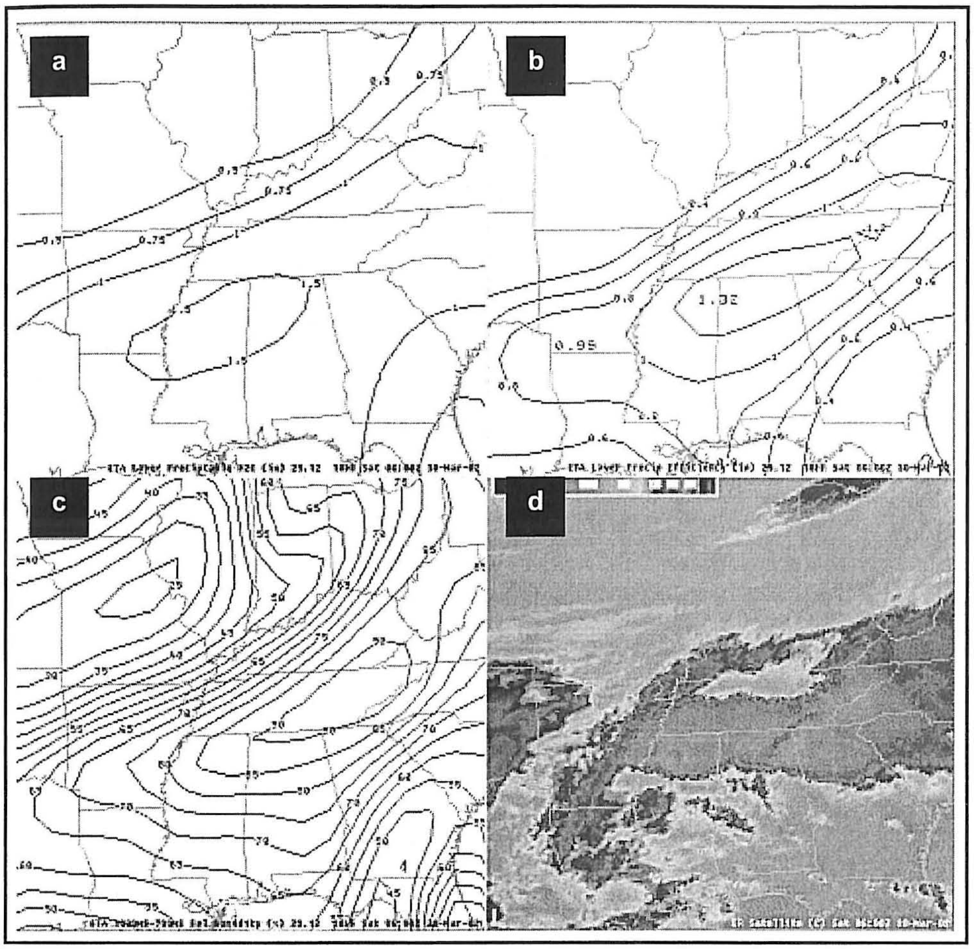

Fig. 7. a) Eta 18-h forecast of precipitable water (in.), valid at 0600 UTC 30 March 2002; b) as in a, except for precipitation efficiency (in.); c) as in a, except for 1000-700 hPa mean relative humidity (RH); and d) enhanced GOES IR image for 0600 UTC 30 March 2002.

and dewpoints. Further study will substantiate additional value in using the PE parameter for other regions across the United States.

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NWA SCHOLARSHIPS AVAILABLE

ANNOUNCING: The Arthur C. Pike Scholarship in Meteorology

Thanks to a generous donation from the estate of the late Dr. Arthur C. Pike, your elected NWA Council members developed a college scholarship fund in 2000. This is the fourth year it is being offered.

Offering: 1 scholarship per year in the amount of $1000.

Administration: The NWA Education Committee will administer the scholarship selection. Applications close 15 April 2004 and the scholarship designee will be notified by mid-May.

Eligibility: Undergraduate and/or Graduate students. Undergraduates must be classified at least as a junior for the semester beginning in September 2004. This will allow second semester sophomores to apply for the scholarship. If the student is classified as a senior they must either have one more fall (Sep. - Dec.) semester to complete after the scholarship is awarded or document that they have been accepted into graduate school.

Award Criteria: The scholarship will be based on:

a) official college transcripts (academic achievement),

b) two letters of recommendation (at least one from a current or former meteorology professor),

c) a letter (not longer than one page) from applicant describing their involvement/interest in meteorology.

Logistics: Scholarship money will be transferred following the financial guidelines of the college or university involved.

Applications for the NWA Arthur C. Pike scholarship to be awarded in 2004 must be returned to the NWA office by 15 April 2004. The office address is on the application form. The application form is available to copy online at http://www.nwas.org/scholarship_app.html or it can be obtained from the NWA office (434) 296-9966.

ANNOUNCING: The David Sankey Minority Scholarship in Meteorology

To increase diversity and the numbers of students from underrepresented ethnic groups pursuing studies in meteorology, the National Weather Association Council established a college scholarship fund in 2002. This is the second year this scholarship is being offered.

Offering: One scholarship per year in the amount of $1000.

Administration: The NWA Education Committee will administer the scholarship selection. The NWA office will announce the call for applications in January each year, applications will close 15 April 2004 and the scholarship designee will be notified by mid-May.

Eligibility: Any minority undergraduate or graduate student going into their sophomore year or higher grade and majoring in meteorology may apply. If the undergraduate student is classified as a senior they must either have one more fall (Sep. - Dec.) semester to complete after the scholarship is awarded, or they must document that they have been accepted to graduate school. Ethnic minorities are defined on the application form.

Award Criteria:

The scholarship will be awarded based on:

a) official college transcripts (academic achievement),

b) two letters of recommendation (at least one from a current or former meteorology professor), and

c) a letter (not longer than one page) from the applicant describing their involvement/interest in meteorology.

Logistics: Scholarship money will be transferred following the financial guidelines of the college or university involved. If there aren't any financial guidelines from the school, NWA will make the $1,000 check payable to both the student and the education institution at the beginning of the September - December school term.

Applications for the NWA David Sankey Minority Scholarship in Meteorology to be awarded in 2004 must be submitted to the NWA office by 15 April 2004. The application form is available to copy from the NWA Web site at http://www.nwas.org/dsscholarshipform.html or it can be obtained from the NWA office (434) 296-9966.