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# USE AND EXPANSION OF AN OBJECTIVE OROGRAPHIC QPF AID

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## 1. INTRODUCTION

Quantitative precipitation forecasts (QPF's) for river basins are of great importance to river forecast centers and reservoir operators. QPF's in topographically complex areas like California must account for terrain effects on precipitation. Mean annual precipitation ranges from less than 15 inches in parts of the Sacramento Valley to over 80 inches in some of the wettest locations in the Sierra Nevada at the same latitude. This paper briefly describes an objective orographically-based QPF aid which the California-Nevada River Forecast Center (CNRFC) has been running for the last four years. The method produces QPF's in six-hour blocks and is also converted to input for use with new QPF preparation software (Mountain Mapper) from the Colorado Basin River Forecast Center (CBRFC). See Henkel and Peterson, 1996. An example of results for the flood period of late December, 1996 to early January, 1997 is given and some verification statistics from 1995 are mentioned.

## 2. METHOD

The method uses prognostic soundings (i.e., profiles of wind, humidity, and temperature) from the NCEP ETA, AVN, and MRF models and computes QPF in 6-hour blocks out to 4.5 days into the future. It is partially based on a simple orographic model by Rhea (1978) originally developed for western Colorado for both QPF and seasonal summation purposes. A similar QPF method based on the above model was first developed for Colorado in 1976 and for Blue Canyon, CA in 1979. The first 72 hours of output is reformatted as "first guess" QPF input to Mountain Mapper. Data acquisition, computation, and transmission of output to forecast offices is automated.

### 2.1 Orographic Model Description

The orographic model is steady state, multi-layer (with 50mb vertical increments), and two dimensional. It assumes air parcels in all layers travel parallel to the 700mb wind direction with the layer speed component that is aligned with the 700mb flow and it requires a separate 5km interval grid orientation for each 10 degree difference in 700mb direction. The model has no dynamics and no explicit microphysics. For a layer forced up or down by the terrain the condensation or evaporation is computed and part of the condensate precipitates (based on an empirical precipitation efficiency value) while the rest moves on downstream with the parcel. Over the next grid interval downstream, the same constant fraction of both imported and locally produced condensate precipitates and the rest goes on downstream. For sinking motion, partial or total evaporation occurs. If the parcel becomes subsaturated, saturation deficit is computed. Precipitation into a dry layer partially or totally evaporates. Computations start with the highest layer and work downward. They step forward along the line from grid point to grid point. When a line is completed, calculations proceed along the next grid line, etc. Output is precipitation at each grid point or area averaged precipitation over desired basins and/or mountain ranges. An assumption of duration is necessary since the model is steady state. By design, a key characteristic of the model is output in patterns which are quite dependent on the 700mb wind direction.

The model requires observed or predicted soundings of wind, humidity, and temperature as input.

Preliminary calibration when the model was first applied to part of northern California was to total precipitation (i.e., not just to "orographic" precipitation, for lack of the ability to separate observed precipitation into causal components). However, the model, by itself, will not produce precipitation over the broad valley floors as it has no mechanism for doing so.

### 2.2 The Basic QPF Objective Aid

The basic objective QPF aid derived from the wind-direction sensitive model described above doesn't require full orographic model runs each time. Rather, it is derived based on the repeatability of 700mb wind direction-dependent orographic precipitation patterns over a basin or mountain range and with precipitation magnitudes scaled by predicted wind speed, moisture depth, and temperature. The method makes use of (a) stored reference table values from full orographic model runs (made one time only) for each 10 degrees of 700mb wind direction with a warm, wet, and windy reference sounding of known wind, moisture, and

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temperature profiles (characterized by 700mb wind speed of 50 kts, 700mb temperature of 0C, and moisture from 1000mb to 450mb) and (b) a quantitative comparison of the appropriate prognostic NCEP model sounding to the reference sounding with respect to profiles of wind, temperature, and humidity. This quantitative comparison yields a "correction factor" (multiplier) for scaling the reference model value for the predicted 700mb wind direction. The sounding comparison is made by running both the prognostic and reference soundings up an inclined plane of known, fixed dimension always aligned with the 700 mb wind direction. Condensation rate is calculated and summed layer by layer for each of the two soundings. The "correction" factor consists of the ratio of the predicted-to reference- condensation rate. Values of the correction factor range from zero for dry predicted soundings to over 1.0 for exceptionally windy, warm, and wet soundings.

### 2.3 Additional Modifications

Two additional modifications are routinely made to the computed precipitation. The first modification is a correction for low relative humidity in the 1000mb to 500mb column and is basically used as a substitute for a duration factor correction. The second is a correction for weak wind speeds in the lower levels to make the procedure more similar to a full orographic model run. Each of these "corrections" decreases the computed precipitation amounts.

The humidity "correction" is a multiplier to apply to the original computed amount. It ranges from zero (0.0) for mean RH of <60% to 1.00 for mean RH of 95% or greater. Between 60% and 70%, it increases linearly from 0.0 to 0.60. From 70% to 95%, it increases linearly from 0.60 to 1.00. These humidity corrections are similar to those that had been applied in past years before the method was fully computerized.

The rule for applying the low-level wind speed correction is to assume that layers whose component wind speed along the direction of the 700mb flow is less than 2.5 m/s do not "go over the mountain". This test is applied to the lower 1 to 4 pressure levels (1000mb to 850mb), starting from the bottom and working up until the lowest layer with > 2.5 m/s is found. This has two impacts, both negative, on the computed vertically integrated condensation rate. First, these "dead" layers that don't go over the mountain receive no lift. Second, the top of the highest "dead" layer becomes the effective height of the base of the inclined plane, thus decreasing the total amount of lift (and condensation) up the inclined plane for all layers..

## 3. APPLICATION

NCEP model prognostic soundings are used to automatically compute QPF for 30 river basins and/or mountain range areas across California either once or twice daily.. The number of areas has grown from 11 over central and northern California for the 1993-94 season to the present thirty distributed throughout the state.

Output is now automatically converted to input to the new Mountain Mapper software for display at CNRFC and NWS forecast offices as one form of objective QPF guidance.

## 4. PRELIMINARY VERIFICATION AND SOME RECALIBRATION

Some verification statistics were calculated for 8 of the original 11 areas for January and March, 1995, two months that experienced episodes of severe flooding. For five of the eight areas , linear correlation coefficients between computed 24-hour basin average QPF's and observed station group averages were greater than 0.8 with some as high as 0.87, and all were greater than 0.7. Some sample verification of 6 hour QPF's were generally less, but still at or above 0.7.

Regression equation slopes indicated some areas with overprediction but others with underprediction. These findings were considered in making some additional bulk corrections by area for use in the 1995-96 and subsequent wet seasons to improve the usefulness of this automated method..

It should be mentioned that the 700mb wind direction-dependent reference table values for the Lake Shasta area come from forecast experience rather than the orographic model. They are still direction-dependent, though, and observation repeatedly verifies the direct wind speed dependence of the precipitation rates in that area.

## 5. EXAMPLE OF THE OROGRAPHIC METHOD COMBINED WITH MOUNTAIN MAPPER

Exceptionally heavy rains occurred between December 26 , 1996 and January 3, 1997 over central and northern California, particularly in the mountains, producing severe flooding. Statewide, damage estimates run as high as two billion dollars. Orographic QPF calculations were made throughout this period and were available to CNRFC and several forecast offices.

The Mountain Mapper software package was not completely operational over the CNRFC area during this flood period, but insertion of the orographic output into this package will illustrate the potential usefulness of combining orographic calculations and Mountain Mapper to get an area-wide display of the distributed objective QPF thus generated.

Mountain Mapper has been designated as the official method over the NWS Western Region beginning in October, 1997 to generate mean basin average values of QPF for delivery to the river forecast centers in the region. It is designed to areally distribute QPF specified at a relatively small number of points by the NWS forecast offices by generating QPF at all HRAP grid points (on an approximate 4km grid interval) and averaging these values over river basins for use in river forecasting and reservoir operations. Mountain Mapper compares QPF values specified at a few points to the point's gridded climatological normal and then generates QPF at all grid points using weighted averages of fraction of monthly normal from QPF specified at five points nearest to the grid point in question. The gridded monthly normal precipitation files were generated by the PRISM method (Daly, et al, 1994). Mountain Mapper will accept objective estimates of QPF from up to two sources; for instance, direct NCEP model QPF, or the orographic method which is the subject of this paper.

Placing the orographic QPF for a 36 hour period during the height of the flood period into Mountain Mapper and comparing the generated values over the American and Feather River Basins to observations at a substantial number of measurement locations, indicated about 70% of the areal variance of observed precipitation was explained by the orographic QPF when distributed by Mountain Mapper. Furthermore, no major bias in amounts was noted.

Performance of the method for the whole storm period can be summarized by displaying a map of the summed 24-hour orographic QPF's side by side with the observed map (Figure 1). Both the orographic and observed data have been distributed by way of Mountain Mapper. The individual 24-hour periods of orographic QPF that make up the sum were each valid 12 to 36 hours into the future. ETA model predicted soundings were used as input to the orographic routine.

Comparison of predicted (Figure 1a) to observed precipitation (Figure 1b) shows quite good agreement in general with respect to location and amount. The contour interval on each map is 6 inches. The largest contour on both maps is 42 inches. There is some degree of overprediction in the southern portion of the Sierra Nevada (i.e., over the southeast part of the figures) The largest measured amount of precipitation during this nine day period was 42 inches at Bucks Lake in the Feather River Basin.

## 6. CONCLUSIONS

This inexpensive, completely automated orographic QPF calculation method described provides useful objective QPF guidance. Its usefulness is further enhanced by feeding it into the Mountain Mapper software which can extend its indications to areas other than just those for which it specifically made calculations. It is a useful way of making quantitative use of the predicted soundings from the large scale NCEP operational models to obtain finer-scale QPF estimates.

## REFERENCES


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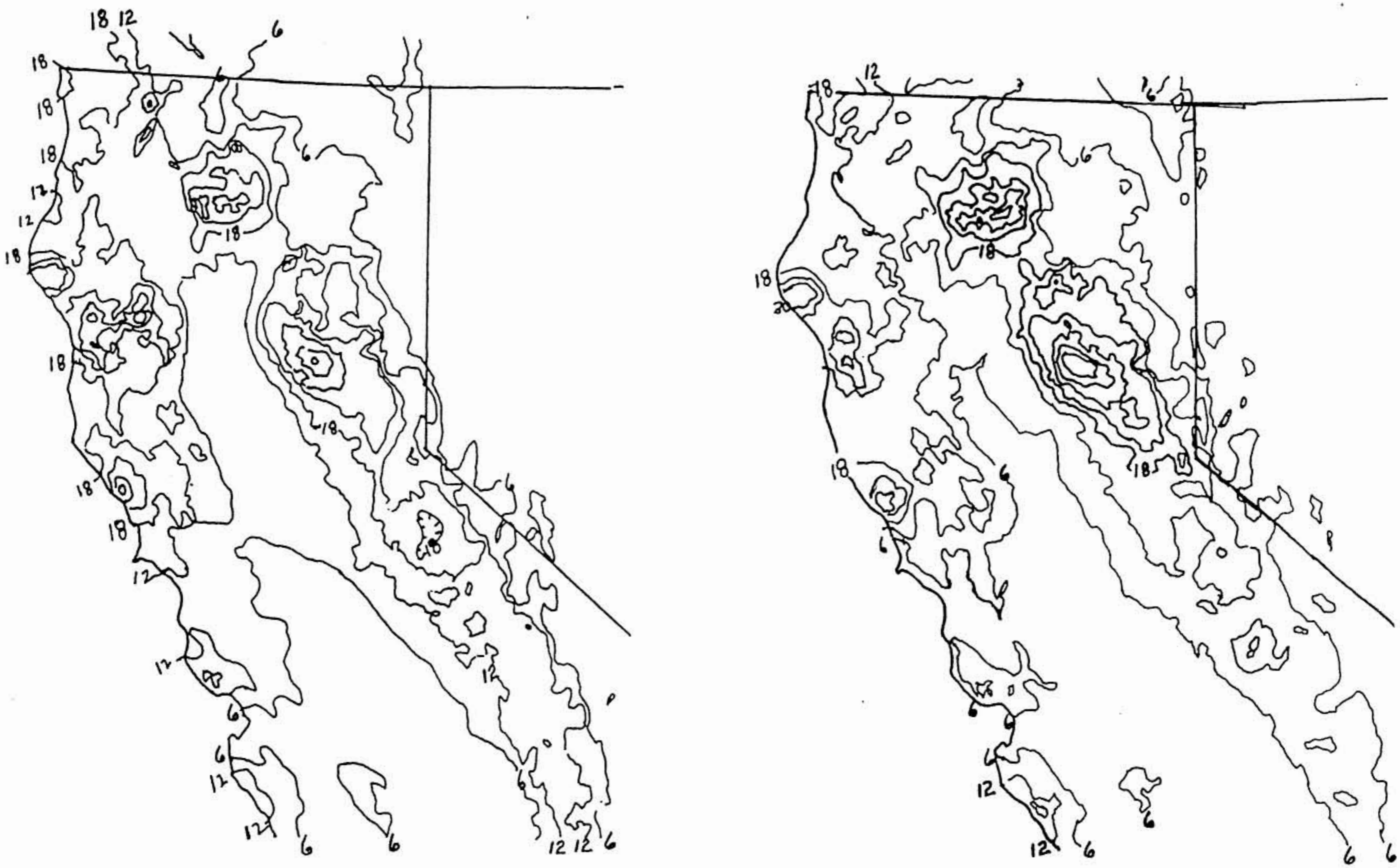

**(a) Predicted** **(b) Observed**

Figure 1. Summations of predicted (a) and observed (b) precipitation for nine days (December 26, 1996 through January 3, 1997). Contour interval is 6 inches. Predicted and observed have both been distributed via Mountain Mapper. Predicted map is composed of nine 24-hour periods of orographic QPF valid 12 to 36 hours into the future using ETA predicted soundings as input..