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AN OBJECTIVE OROGRAPHICALLY-BASED QPF AID FOR CALIFORNIA

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ABSTRACT

The California/Nevada River Forecast Center needs quantitative precipitation forecasts (QPFs) expressed as river basin averages. This Technical Attachment briefly describes an orographically-based QPF aid and its application, and presents results from the 1995 heavy precipitation periods in California. The method uses gridded prognostic data from the NMC models as input and is partially based on a simple orographic precipitation model (Rhea, 1978). QPFs are derived based on the repeatability of 700mb wind direction-dependent orographic precipitation patterns over a basin and with precipitation magnitudes scaled by wind speed, moisture depth, and temperature from a quantitative comparison of predicted soundings to a reference sounding used to derive reference tables of orographic model precipitation. Calculations with the basic QPF aid began in the fall of 1993 for eleven areas in California. Input data were grid point data from the Eta, NGM, and AVN models for appropriate locations. By the beginning of March 1995, the procedure was being automatically run twice daily on an HP-755 and automatically sent to the Monterey WFO. Eight of the 11 areas were judged to have adequate measurement data to warrant an attempt at some verification. Verification has been mostly for 24-hour periods 12 to 36 hours into the future, covering most of January and March 1995, and including both major flooding episodes across California. Summary statistics for each of the eight areas showed there were no linear correlation coefficients less than 0.7 and 5 of the 8 were greater than 0.8. Many of the worst outliers were related to problems with the synoptic scale model output. Results show there is sufficient predictive skill in the technique to continue its use, at least while awaiting the routine, timely availability of mesoscale model QPFs on a similarly fine scale of topography. The method appears to be a useful way of employing the current generation of gridded data from the larger scale models as an objective precipitation forecasting aid.

Introduction

The California/Nevada River Forecast Center (CNRFC) and some other agencies such as the Bureau of Reclamation require quantitative precipitation forecasts (QPFs) expressed as river basin averages. In a topographically complex area like California, this imposes the necessity to account for terrain effects on precipitation. From the California mean annual precipitation map (Fig. 1), the dominant influence of topography is obvious, with less than 15 inches in parts of the Sacramento Valley and over 80 inches in parts of the Sierra Nevada at the same latitude.

This Technical Attachment briefly describes an orographically-based QPF aid and its application, and presents results from the 1995 heavy precipitation periods in California.

Method

The method uses gridded prognostic data from the NMC models as input and is partially based on a simple orographic precipitation model (Rhea, 1978) originally developed for western Colorado for both QPF and seasonal summation purposes. A similar method, derived from this model, was first used in Colorado in 1976 and for Blue Canyon in the Sierra Nevada in 1979. While the QPFs are related to the orographic model precipitation, they are not produced from direct running of the model programs on a daily basis. They are derived based on the repeatability of 700mb wind direction-dependent orographic precipitation patterns over a basin and with precipitation magnitudes scaled by wind speed, moisture depth, and temperature.

The basic QPF objective aid uses (a) a set of reference tables of orographic model-produced precipitation and (b) a scaling factor derived from a quantitative comparison of predicted soundings to the <u>reference sounding</u> which was used to derive the reference tables of precipitation mentioned above. Items that are <u>calculated only once</u> and then placed in the QPF program for subsequent use are (a) the reference tables of orographic model precipitation and (b) a reference value from a calculation which incorporates the profiles of moisture, wind, and temperature from the reference sounding. The steps in the procedure are described below, following a brief description of the orographic model.

<u>Orographic Model Description</u>

This model is steady state, multi-layer (in 50mb layers to 450mb), has a 5 km horizontal grid interval (with topography derived from USGS 1 minute data), and has no dynamics or explicit microphysics; rather, it keeps track of the condensation, evaporation, and fractional precipitation layer by layer as the parcels move over the topography from one grid point to the next along the direction of the 700mb flow (by assumption). Precipitation efficiency, E, is the fraction of total condensate (that imported plus that locally produced when traversing one grid interval) which precipitates. The remaining fraction , 1-E, becomes the imported condensate for the next grid interval downstream. Precipitation efficiency is a parameter which can be varied to better match the climatological areal distribution of precipitation when setting up the model over a new area. Calculations proceed along one grid line at a time. Total precipitation from all layers is calculated at each grid point after accounting for possible sub-cloud evaporation. Precipitation can then be summed and averaged over any desired area (or basin). A key feature of the model-produced precipitation patterns is their strong dependence on 700mb wind direction. By design, a different topographic grid must be used for different 700mb flow (unique to each 10 degrees of direction).

The model needs an observed, predicted, or contrived sounding as input.

The Basic QPF Objective Aid

First. a set of wind-direction dependent orographic model runs are made for a given basin, using a "reference sounding" of known characteristics of deep moisture, strong winds, relatively warm temperature, and a known (assumed) precipitation duration. These runs use model topographic grids with a 5 km horizontal interval. The only thing that varies from one run to the next in making this set of runs is the profile of wind direction. A set of model "reference" precipitation basin averages is obtained with one value for each 10 degree class of 700mb wind direction (i.e., 180, 190, 200 ....340, etc.). This is done only once. These direction-dependent model basin average "reference" precipitation values are then entered as a data table to be "referred to" in the QPF program which is subsequently used in the rest of the scheme.

Second, the appropriate predicted sounding from NMC gridded data is quantitatively compared to the "reference sounding" with respect to wind speed, moisture depth, and temperature. The objective of this comparison is to derive a "correction factor," i. e., a multiplier to apply to the appropriate reference precipitation amount in the program's data table to calculate the QPF. The method devised to make this comparison makes use of an inclined plane of known, fixed dimension (1.2 km of lift in 70 km of travel) which is always aligned with the 700mb flow, rather than the detailed orographic model topography. The steps are as follows:

1. The "reference sounding" from the orographic model reference runs above is moved up the sloping inclined plane layer by layer. The condensation supply rate, CSR, from this process is vertically summed. This vertically summed "reference" CSR, refCSR, is stored as a constant to refer to in the QPF program. This is done only once, not for every prediction time, because the reference sounding does not change except for wind direction and the inclined plane is always aligned with the 700mb flow.

2. The inclined plane, aligned with the predicted 700mb flow, is used with the predicted gridded data sounding to compute the predicted CSR, predCSR.

3. The "correction factor", CF, or multiplier, is then: predCSR / refCSR. It can have values from zero (dry conditions) to greater than one (for extremely windy, wet, warm conditions).

Third, the predicted 700mb wind direction is used to find the appropriate "reference" basin average, RBA, from the orographic model reference tables in the program and the QPF is then:

$$QPF = (RBA) \times (CF).$$

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, while the second is a correction for weak wind speeds in the lower levels. This second modification decreases the "lift" for conditions of very light wind components oriented along the direction of the 700mb flow. It was invoked 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. This humidity correction is approximately the same as had been applied outside the computer by the Bureau of Reclamation forecaster (Rhea) in past years.

The rule used 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 2.5m/s, or 5kts, 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 greater than 2.5 m/s is found. This has two impacts, both negative, on the computed vertically integrated CSR. 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.

Computed precipitation amounts are written to file and printed for the unmodified amounts, the humidity-corrected amounts, and the low-level wind- plus humidity-corrected amounts.

Experience with these objective aids from this past winter indicates that in most cases, it is best to apply both corrections to the coastal mountain areas where the potential orographic lift is comparable to the height of the inclined plane used in this scheme, but only the humidity corrections for the higher Sierra Nevada. However, both corrections may also be needed for the Sierra when the only thing supporting precipitation is a flow of moist air (e.g., with no dynamics and surface high pressure with very weak low-level flow).

Application

Calculations with the basic QPF aid began in the fall of 1993 for the 11 basins or mountain ranges shown in Fig. 2. The humidity and low-level wind corrections were invoked by January, 1995. Input data for the required predicted soundings were grid point data from the Eta, NGM, and AVN models for appropriate locations. These data were made available in ASCII form and were downloaded via Internet from Salt Lake City. Output was printed for 6- hour intervals to either 48 hours or 72 hours. Output was also averaged for the three models (NGM, Eta, AVN). Most of the time, runs were made using data from both the 00Z and 12Z NMC model run times. By the beginning of March 1995, the procedure was being automatically run twice daily on an HP-755 with the crontab facility and automatically sent to the Monterey WFO.

Verification

QPF verification is very difficult in mountainous areas, especially when QPFs are expressed as basin averages, as required by the RFC, but the observed precipitation is only measured at a relatively small number of points. Of the 11 areas in Fig. 2, only 8 were judged to have adequate measurement data to warrant an attempt at some verification. Simple group averages from the stations within each area were used as an index of the observed precipitation. A check on the historical station group mean annual averages compared to the basin mean annual precipitation derived from GIS overlays of the mean annual isohyets and basin boundaries yielded surprisingly close agreement of the station averages to the basin means. Only one of the 8 verification areas showed more than a 15% difference. This lends some confidence to the verification statistics. The number of stations averaged together ranged from 3 to 13, depending on the area.

Most of the verification has been for 24-hour periods covering most of January and March 1995, and including both major flooding episodes across California. The 24-hour QPFs were for the period 12 to 36 hours into the future. More limited verification of 6-hourly amounts has been accomplished for 2 of the 8 areas. The QPFs were the average of the orographic computations calculated from the individual NGM, Eta, and AVN gridded prognostic soundings.

Figures 3 and 4 show scatter plots of predicted (x-axis) vs. observed station averages (y-axis) for the Eel Basin and Shasta Inflow area. Correlation coefficients are above 0.85. Some overprediction is evident. Figure 5 shows a similar plot for the Upper San Joaquin above Friant Dam with a correlation coefficient of 0.76. The five worst "outliers" on Fig. 5 are from two days in March and three days in January. Similar problems were exhibited for these same days by the meso-Eta and another mesoscale model which use the AVN or ETA for lateral boundary conditions. This implies a significant effect from problems with the synoptic scale model output data for those days. When these days are eliminated from the sample, the correlation increases to 0.84 for the San Joaquin.

Table 1 lists the summary statistics for each of the eight areas for which verification has been completed so far. No correlation coefficient was less than 0.7 and 5 of the 8 were greater than 0.8. Five of the 8 intercepts were less than 0.1 inch in absolute value and none were greater than 0.3 inch. The degree of overprediction apparent for the Smith Basin was about as expected from early experience with the method and for which similar modifications were operationally being made before making use of these QPF indications. A comparison of mean annual station average to GIS-derived basin mean annual average, however, indicates a 26% greater basin mean than for the station mean. This suggests the orographic QPF may not have been quite as severely overpredicting as the station data would indicate. The underprediction over the Russian Basin was similar to what was expected, again from early experience with the method, and for which modifications were made before using the data during the season.

Preliminary verification of 6-hourly amounts was made for the Eel and Shasta areas. Linear correlation coefficients were about 0.7 and 0.8, respectively. These lower values compared to the 24-hour correlation indicate the greater timing errors for short periods of QPFs.

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

Conclusions

An orographically-based QPF aid has been routinely used in the CNRFC for the last two years. Verification work is continuing. However, it is clear that there is sufficient predictive skill in the technique to continue its use, at least while awaiting the routine, timely availability of mesoscale model QPF on a similarly fine scale of topography. Some use will be made of the things learned so far to make some automatic adjustments for systematic over- or under-prediction, thus improving the usability of the output.

Though the technique is very simple, it appears to be a useful way of employing the current generation of gridded data from the larger scale models as an objective precipitation forecasting aid.

References

Rhea, J. O., 1978: Orographic precipitation model for hydrometeorological use. Colorado St. Univ., Dept. of Atmospheric Science, Atmospheric Science Paper No. 287, 221p.

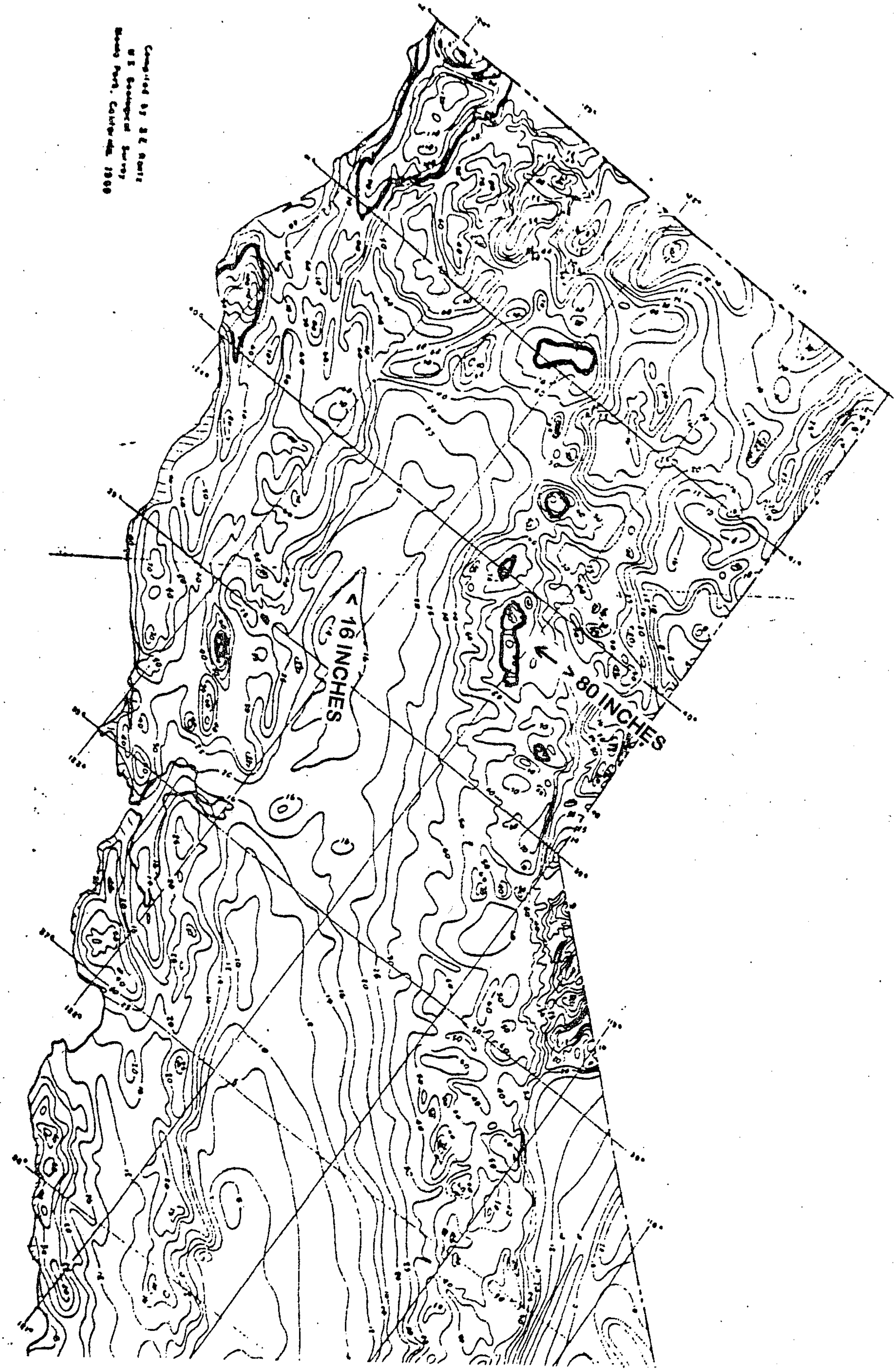

Figure 1. Mean Annual Precipitation Map for Northern and Central California. Areas inside the bold contours have >80 inches. Portion of Sacramento Valley with < 16 inches is labeled.

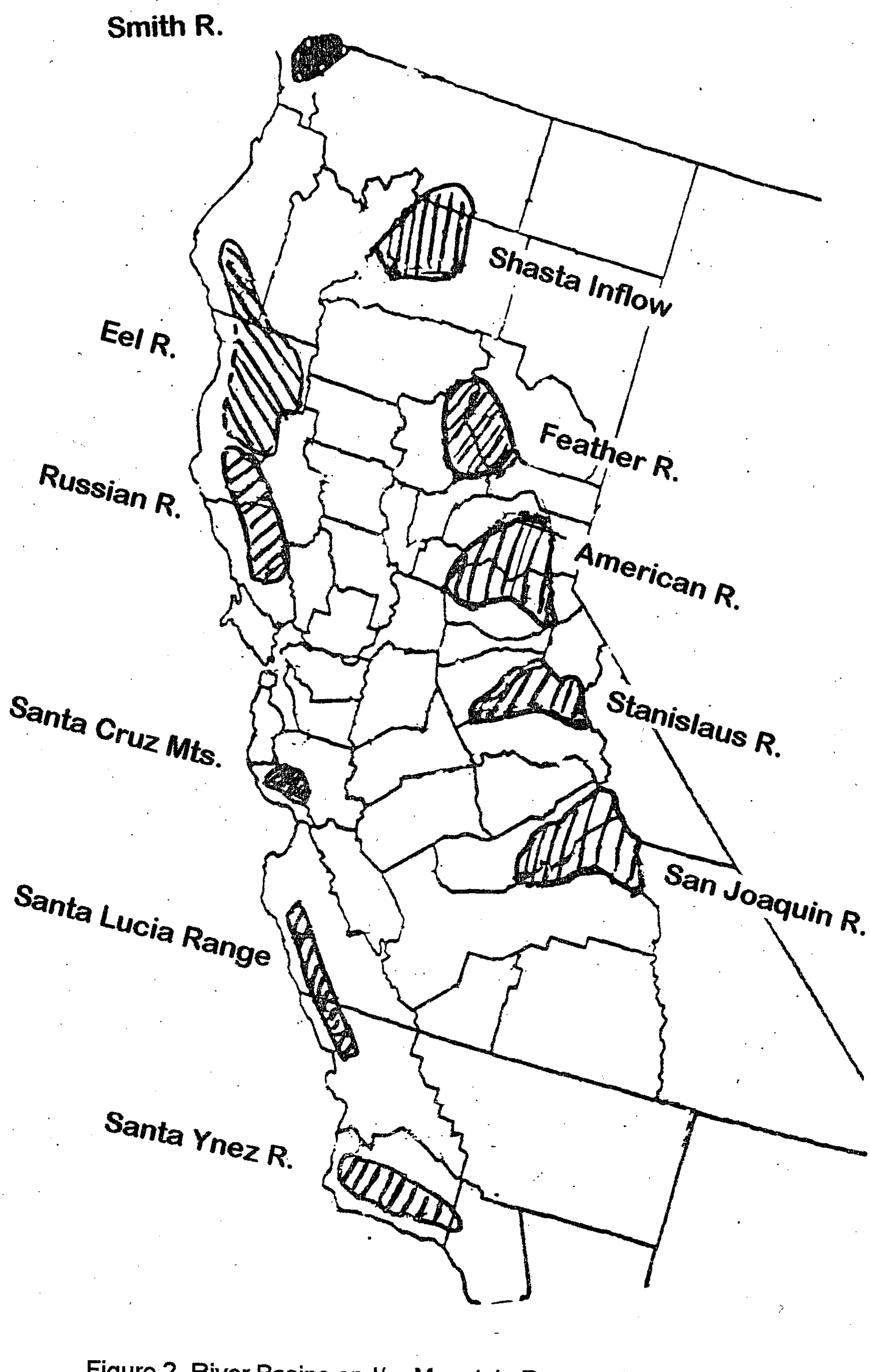

Figure 2. River Basins and/or Mountain Ranges Where Calculations are Made With Orographic QPF Aid.

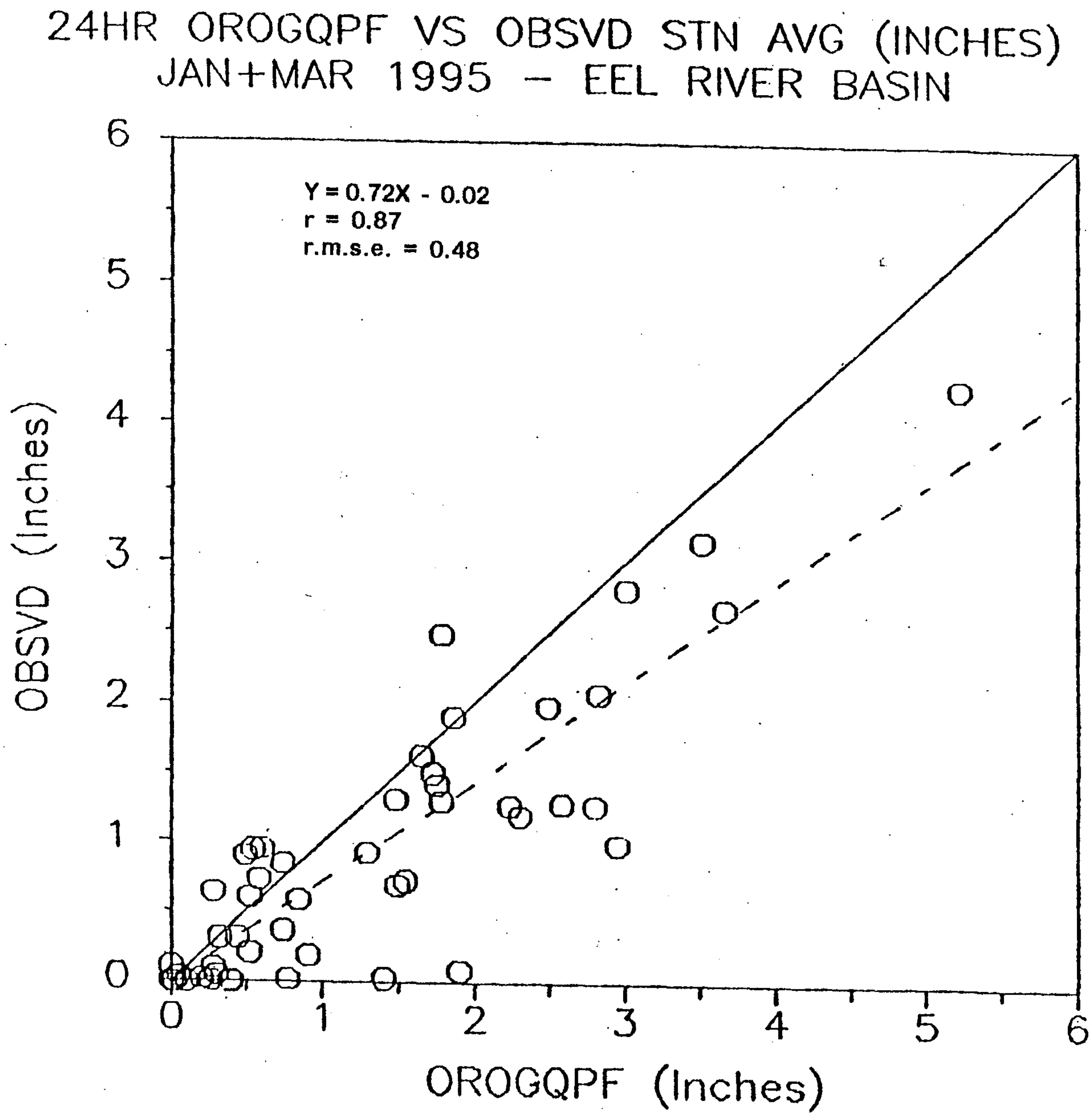

Figure 3. Predicted (X-axis) vs. Observed (Y-axis) for Eel River Basin above Scotia.

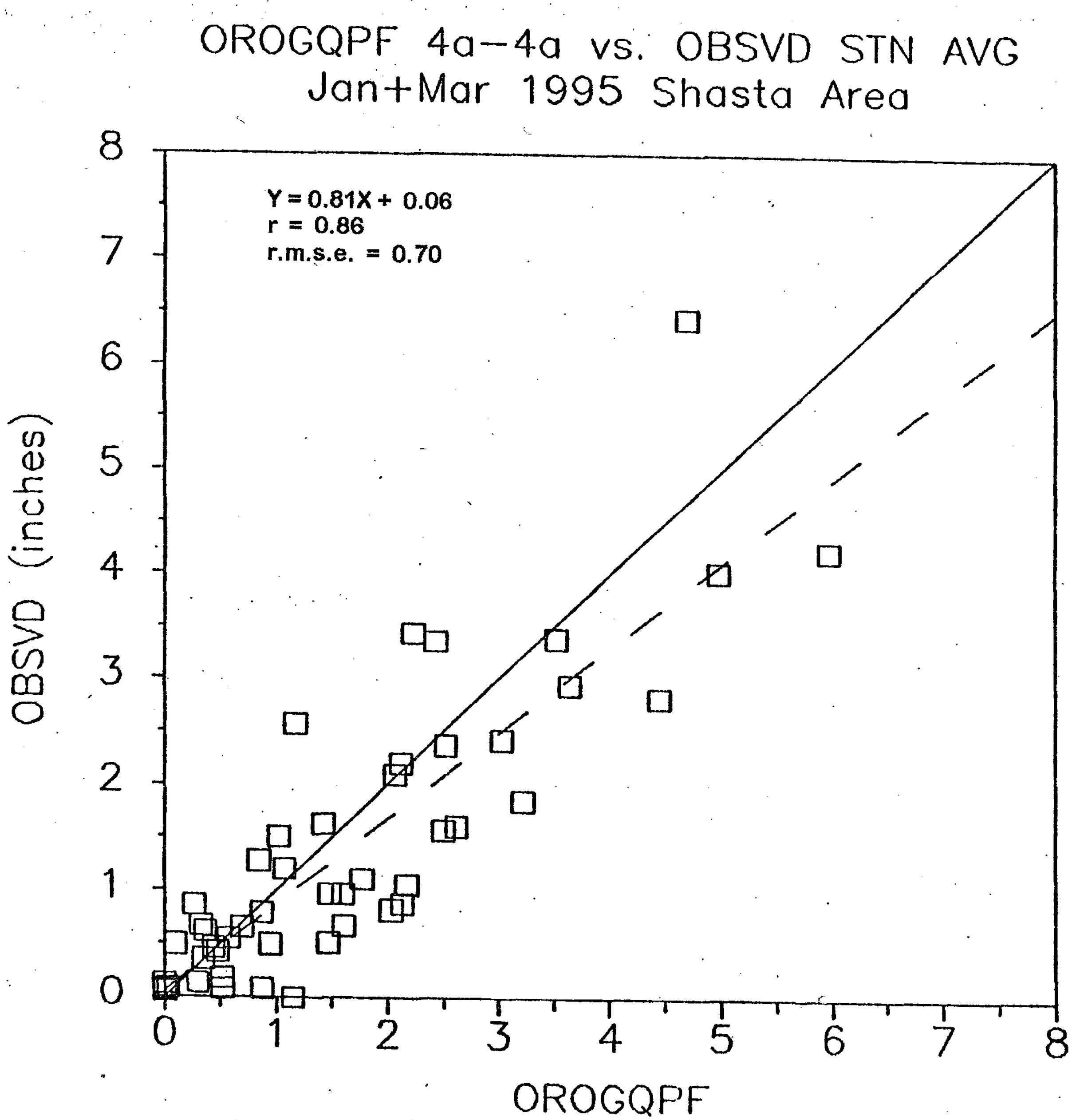

Figure 4. Predicted (X-axis) vs. Observed (Y-axis) for Shasta Area.

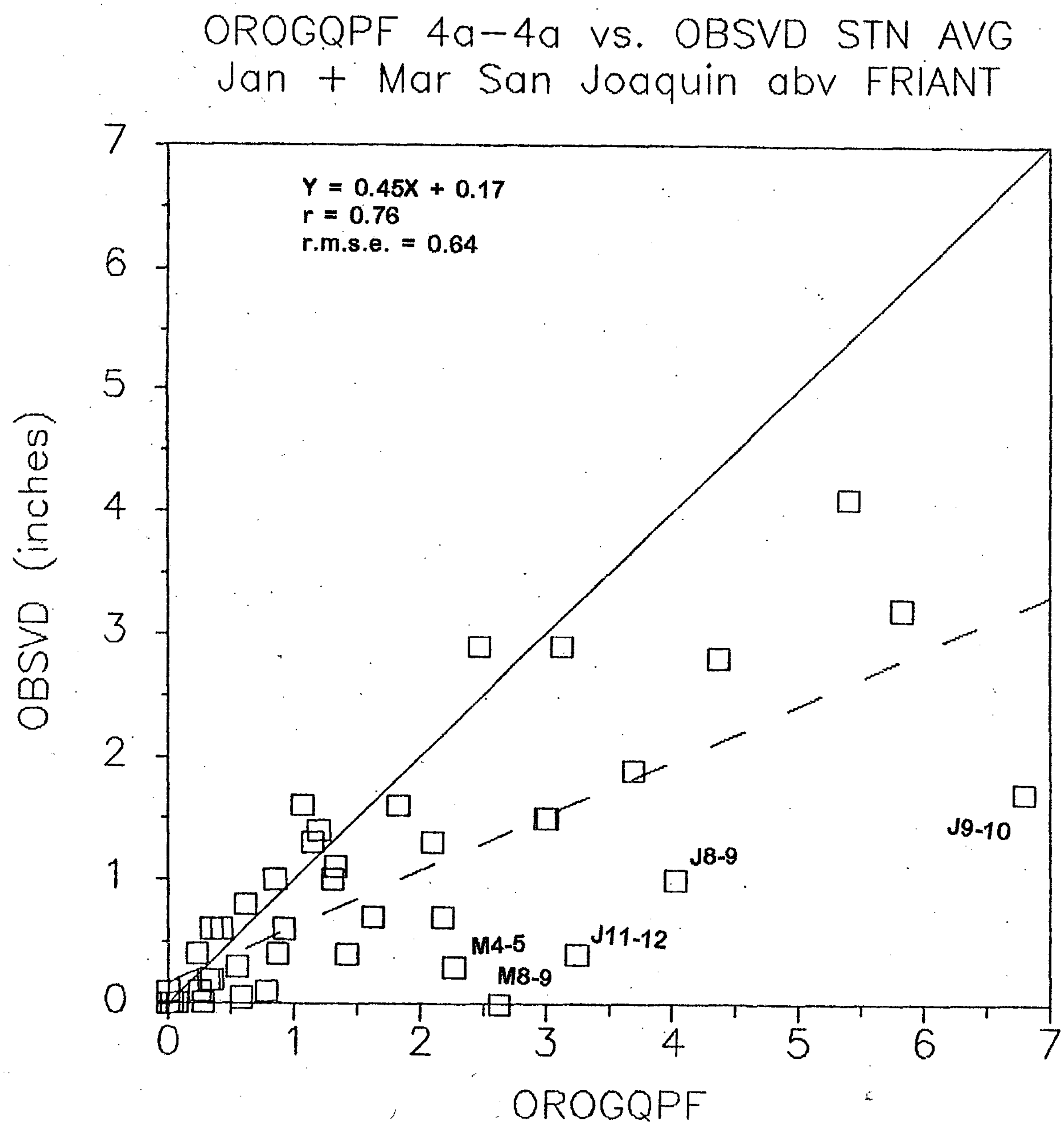

Figure 5. Predicted (X-axis) vs. Observed (Y-Axis)
for San Joaquin River Basin above Friant Dam.

Table 1. Summary Statistics of Verification Studies

AREA	TIME	Correlation Coefficient	r.m.s.e.	Regression Line Slope	Regression Line Intercept
Shasta Inflow	4a - 4a	.86	.70	.81	.06
Feather above Oroville	4a - 4a	.87	.65	.73	-.04
American above Folsom	4a - 4a	.71	.65	.67	.21
SanJoaquin above Friant	4a - 4a	.76	.64	.45	.17
Smith River Basin	4a - 4a	.70	.69	.41	.27
Eel River above Scotia	4p - 4p	.87	.48	.72	-.02
Russian	4a - 4a	.85	.67	1.50	-.02
Santa Lucia Range	4a - 4a	.83	.97	.79	.03