Investigation of Storm Temporal Patterns using Gridded Meteorological Datasets for Hydrologic Modeling

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INTRODUCTION

Rainfall-runoff models require spatial and temporal patterns of precipitation as input. The duration and intensity of this rainfall directly influences the runoff peak and volume generated. In dam safety applications, the spatial and temporal characteristics of extreme storms are typically derived from hydrometeorological reports, storm databases, and frequency analyses available from multiple sources, including, but not limited to, the National Oceanic and Atmospheric Administration, Army Corps of Engineers, and Bureau of Reclamation. The usual format depicting the spatial and temporal patterns is depth-area-duration tables. These tables are typically limited to discrete, 6-hour increments (e.g., Table 1); storm spatial patterns are often limited to storm total isohyetal maps. In reality, we recognize that storms: vary spatially with respect to time; rarely fit into discrete time periods; and, have accumulation rates and event durations that are modulated by multiple factors (e.g., geographical region, time of year, and storm type). In this study, we present a new, applied methodology to explore and examine the variations in precipitation characteristics, including storm durations, in the Friant Dam watershed in California (Figure 1) by comparing point and gridded reanalysis data.

Table 1 – Example depth-duration ratio table from HMR 58.

Table 2.1. *All-season depth-duration ratios for California regions.*

	Duration					
Region	**1**	**6**	**12**	**24**	**48**	**72**
Northwest	0.10	0.40	0.73	1.00	1.49	1.77
Northeast	0.16	0.52	0.69	1.00	1.40	1.55
Midcoastal	0.13	0.45	0.74	1.00	1.45	1.70
C. Valley	0.13	0.42	0.65	1.00	1.48	1.75
Sierra	0.14	0.42	0.65	1.00	1.56	1.76
Southwest	0.14	0.48	0.76	1.00	1.41	1.59
Southeast	0.30	0.60	0.86	1.00	1.17	1.28

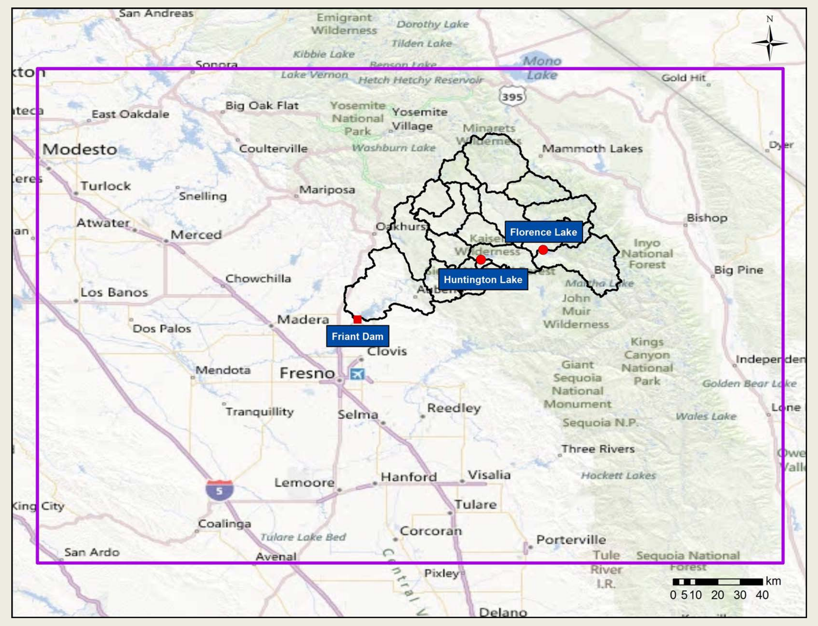

Figure 1 – Friant Dam watershed (black) with sites of interest (blue/white text) and CFS-R domain (purple).

STUDY AREA

The Friant Dam watershed is located in central California, northeast of Fresno (Figure 1). The focus of extreme precipitation events is the winter season when large scale atmospheric rivers impinge on the mountainous terrain, delivering copious amounts of rain and snow. The synoptic conditions conducive to atmospheric river events can last from several days to several weeks, resulting in multiple significant precipitation events that prime the hydrologic characteristics of the watershed (i.e., soil moisture) for major flooding.

DATA

Data applied in the current study include:

- NCDC Hourly Precipitation Data (Table 2)
- Manual Historical Events Analyses (Table 3)
  - Additional NCDC/CDEC Sites (precip/temp)
  - NCEP/NCAR Reanalysis (synoptics)
- CFS-Reanalysis Hourly Gridded Data (Table 4)
  - 36 to 38 N/ 118 to 121 W, from CISL: ds093.1

Table 2 – NCDC hourly precipitation site metadata.

Station	Station ID	Dates Avail	Latitude	Longitude	Elevation (m)
Huntington Lake	043261	1948-2010	37.23	-119.22	2140
Florence Lake	043093	1948-2010	37.27	-118.97	2233

Table 3 – Manually-analyzed synoptic events.

Event #	Start Date	Start Time	End Date	End Time
1	1/10/1980	12 UTC	1/15/1980	00 UTC
2	9/23/1982	12 UTC	9/26/1982	06 UTC
3	2/14/1986	00 UTC	2/19/1986	12 UTC
4	3/9/1995	00 UTC	3/12/1995	12 UTC
5	12/31/1996	00 UTC	1/4/1997	00 UTC
6	11/7/2002	00 UTC	11/10/2002	00 UTC
7	1/1/2006	00 UTC	1/3/2006	18 UTC
8	12/17/2010	00 UTC	12/23/2010	00 UTC

Table 4 – CFS-R Variables.

Variable	Level	Resolution (deg)	Units
PRATE	Ground or water surface	0.313	kg/m^2s
PRMSL	Mean Sea Level	0.500	Pa
P WAT	Atms as Single Layer	0.313	kg/m^2
SPF H	500 hPa	0.500	kg/kg
SPF H	700 hPa	0.500	kg/kg
SPF H	850 hPa	0.500	kg/kg
SPF H	925 hPa	0.500	kg/kg
TMP	1000 hPa	0.500	K
TMP	200 hPa	0.500	K
TMP	500 hPa	0.500	K
TMP	700 hPa	0.500	K
TMP	850 hPa	0.500	K
TMP	Hybrid Level 1	0.313	K
V VEL	500 hPa	0.500	Pa/s
U GRD/V GRD	1000 hPa	0.500	m/s
U GRD/V GRD	200 hPa	0.500	m/s
U GRD/V GRD	500 hPa	0.500	m/s
U GRD/V GRD	700 hPa	0.500	m/s
U GRD/V GRD	850 hPa	0.500	m/s
HGT	1000 hPa	0.500	m
HGT	200 hPa	0.500	m
HGT	500 hPa	0.500	m
HGT	700 hPa	0.500	m
HGT	850 hPa	0.500	m
HGT	Height of 0C Isotherm	0.500	m

METHODOLOGY

RAW DATA COMPARISON

Rainfall statistics were developed using the hourly gauge and reanalysis observations. Since the hourly precipitation gauges applied in the current project are tipping bucket gauges, the CFS-R data were assimilated into 0.10 inch bins to mimic the occurrence of precipitation found in observations (Figure 2). Non-precipitation hours define the start/stop of precipitation with the duration calculated as the length of time of positive precipitation reports. No discretion was applied to allow zero amounts embedded in longer duration precipitation events. This method provides a clear indication of the actual duration of precipitation events without consideration of synoptic forcing.

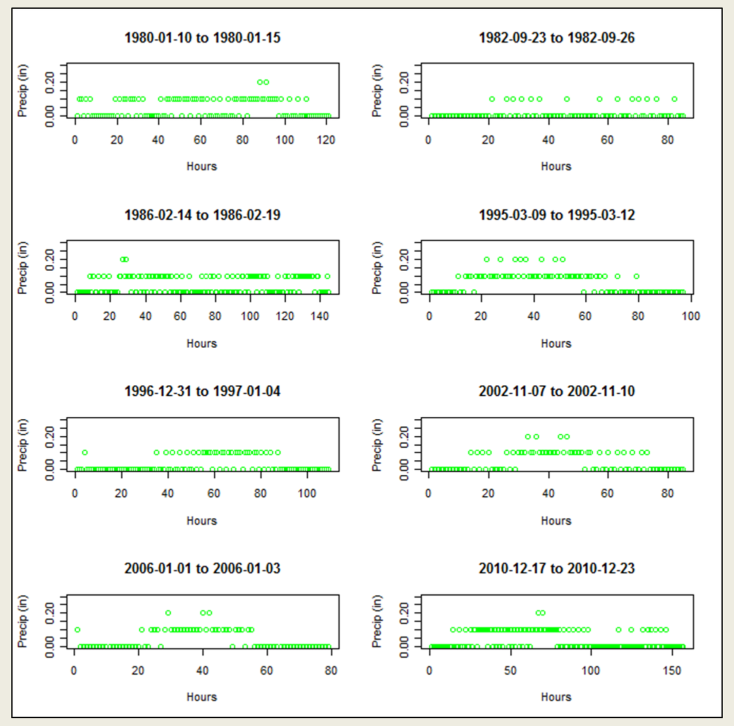

Figure 2 – Gauge-based precipitation time series for the synoptic period for each storm in Table 3.

SYNOPTIC CONSIDERATIONS

To incorporate synoptic considerations into the capture of precipitation event duration, the begin/end times for the eight (8) manually analyzed storms were used to extract CFS-R variables at standard atmospheric levels, including additional parameters with level-specific and integrated column values (see Tables 2 through 4). Hours within the start/stop times of the eight (8) manually-analyzed storms were considered as a precipitating synoptic event (PE), while the six (6) hours preceding and following those times were defined as non-precipitating (NPE). Hours within the PE and NPE are assigned a value of zero (0) and one (1), respectively. By applying a generalized linear modeling (GLM) framework, the definition of a precipitation event can be defined using logistic regression, whereby the binary time series is modeled as a function of the 29 predictor variables in Table 4. Cross-validation is performed to ascertain the skill of the GLM, using a drop-10 percent approach. The GLM is then fit using all eight (8) storms and then applied to each hour for the period 01 January 1979 to 31 December 2010.

RESULTS

MANUAL ANALYSIS VS. CFS-R

An initial comparison of the CFS-R datasets to manual analyses for three storms (i.e., 1982, 1996/97, and 2002 [not shown]) indicate reasonable representation of the precipitation characteristics for each event (Figure 3). The freezing level height and 1000-hPa temperature time series, proxies for snowmelt within the Friant watershed, compare favorably to time-consuming manually-derived fields. Mass curves (shown as percent of storm total), similarly capture the accumulation of precipitation, providing support for application of CFS-R in durational analyses. It should be noted that magnitudes of precipitation, however, are much smaller than observed.

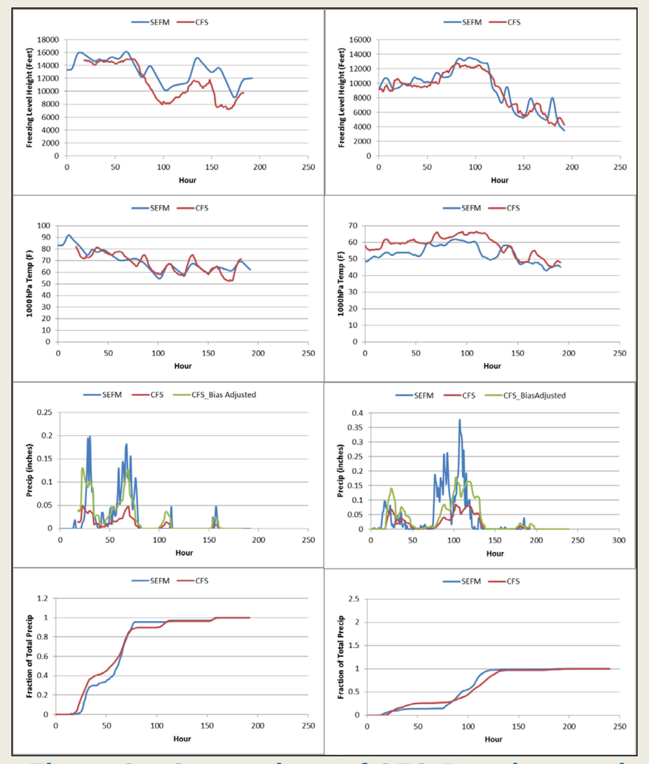

Figure 3 – Comparison of CFS-R and manual analyses of the 1982 (left) and 1996/97 (right) events. Variables noted on y-axis.

RAW DATA

Frequency curves of gauge vs. CFS-R rainfall without consideration of synoptic patterns indicate similar characteristics with predominant durations of less than 24 hours (Figure 4). Only the CFS-R has a single larger event (41 hours). Weighted mean durations for gauge and CFS-R, respectively, are 1.2 and 2.0 hours. The CFS-R indicates a higher relative frequency of short and medium duration events (< 2 and >7 hours), while the gauge has slightly higher frequency between these two durations.

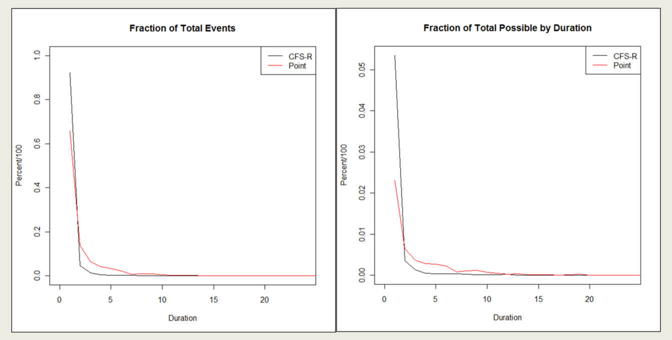

Figure 4 – Comparison of CFS-R and gauge durations (≤ 24h) with no synoptic considerations.

RESULTS (cont.)

GLM DEVELOPMENT & VERIFICATION

The logistic regression from the GLM provides probabilistic estimates of a PE for each hour. Comparison to the eight (8) manually-derived synoptic periods indicates that the GLM captures the event duration, except for the start time of event one (1) (Figure 5, left). The cross-validation is performed for a total of 44,000 predictions (i.e., 500 simulations for 88 dropped values each). The probability of detection is near 100 percent, while the false alarm rate approaches 11 percent. A majority of the false alarms are reflected in the bias to over-predict PE. Only a slight improvement over random chance is indicated, however, with a Heidke Skill Score (HSS) of only 0.06. The measures of performance are shown in the form of a contingency table and related statistics in Table 5 and Table 6, respectively.

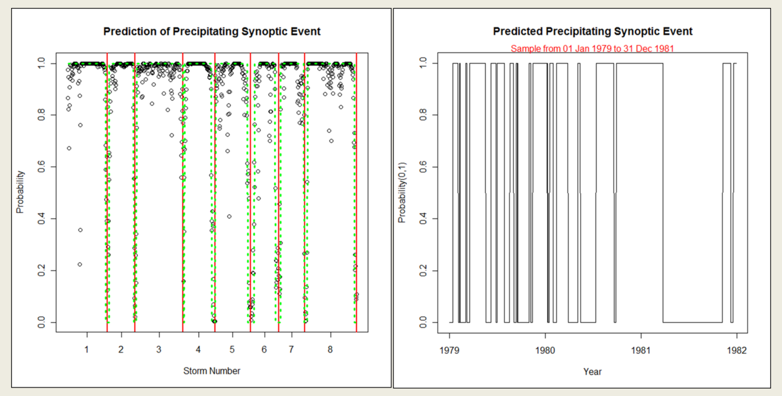

Figure 5 – Comparison of GLM output and manually-derived PE/NPE values for the eight (8) storms (left) and an example of the historical simulation for the period 1979-1981 (right).

Table 5 – Contingency table from cross-validation.

	Pred Y	Pred N	Totals
Obs Y	38760	4709	43469
Obs N	310	221	531
Totals	39070	4930	44000

Table 6 – Performance statistics.

Statistic	Value
PODy	*0.9921*
TS	*0.8854*
ETS	*0.03118*
FAR	*0.1083*
HSS	*0.06047*
PC	*0.8859*
BIAS	*1.113*

GLM APPLICATION

The GLM is then applied to the historical time series of 1979-2010 (e.g., Figure 5, right) and used to evaluate durational characteristics for the Friant watershed. Longer duration events are associated with higher precipitation amounts, as expected (Figure 6, top left). The seasonal distribution of these events is skewed toward the summer season, however, which does not match the observed winter season for extreme and longer duration (>72 hour) precipitation events in California (Figure 6, top right and lower left). Durations, in general, are also lower than anticipated with an annual mean of 15.5 hours (Figure 6, lower right).

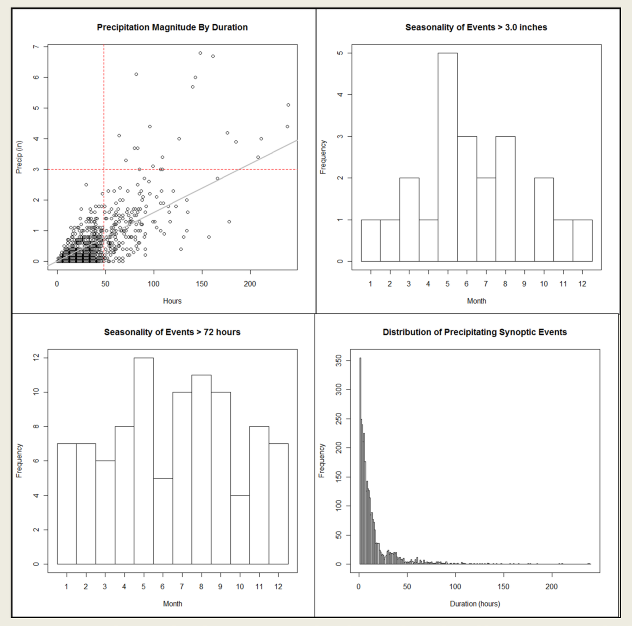

Figure 6 – Durational characteristics, including: precipitation magnitude (top left); seasonal variation (top right, lower left); and, distribution (lower right).

CONCLUSIONS

We examine the characteristics of rainfall through a comparison of observational and CFS-R data sets for the Friant watershed in California. While the accumulative properties for the 1982, 1996/97, and 2002 storms were well captured by the CFS-R data, magnitude differences are evident. Future research should include single cell vs. domain-averaged approaches to evaluate areal smoothing effects. Proxy evaluation of snowmelt parameters (i.e., 1000-hPa temperatures and freezing level heights) suggest the CFS-R may prove useful as a surrogate for manual analyses in flood hazard analysis.

The over-prediction of PE during cross-validation of the GLM elucidates the need for an adapted statistical methodology to better mimic storm duration, perhaps by analyzing a single year manually and fitting the GLM seasonally to account for different synoptic/mesoscale forcing mechanisms. Large magnitude, long duration events in the summer may be a result of the GLM failing to capture sub-synoptic scale convective events, but will require further investigation. The GLM also generates reduced durations for events due to the increased temporal clustering of storms. The synoptic period focus of the CFS-R analysis, however, does appear to better capture the durational characteristics than the raw data analysis with continuous-only precipitation considerations.

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