Physically-Based Estimation of Maximum Precipitation: Preliminary Results on Application to American River Basin for the December,1996-January,1997 Flood Event

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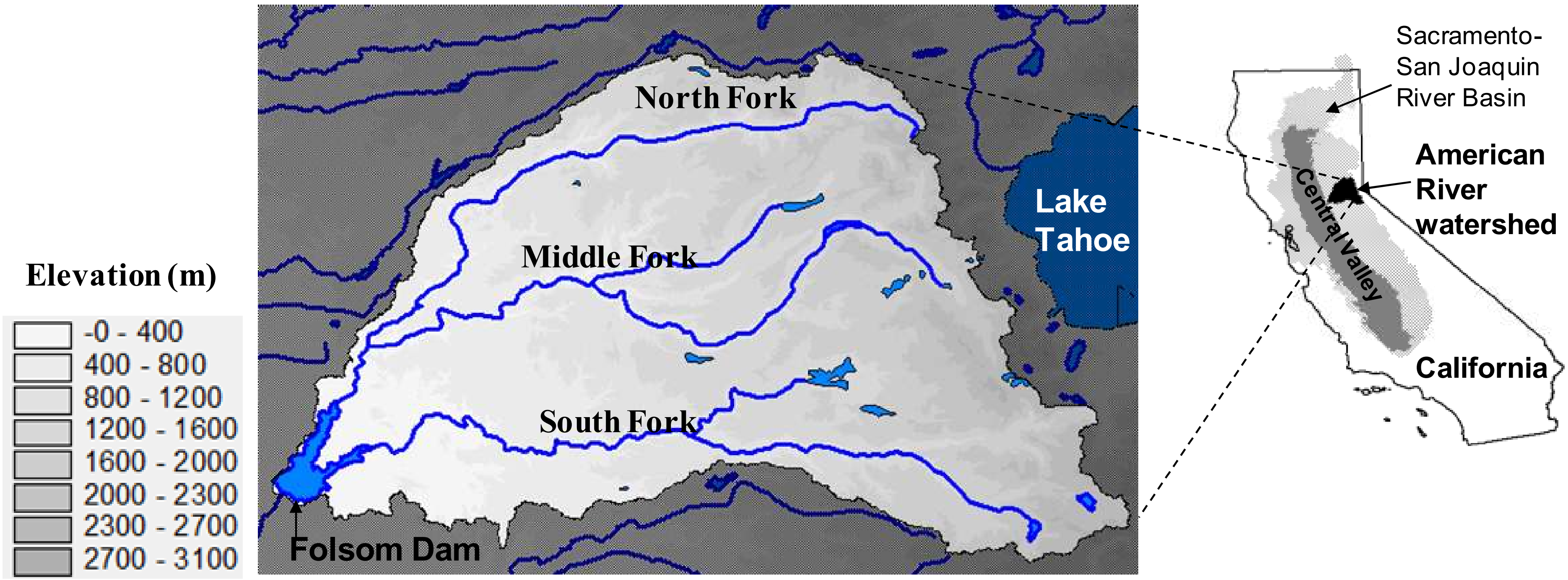
This presentation is based on the paper:

Ohara, N., Kavvas, M. L., Kure, S., Chen, Z. Q., Jang, S., and Tan, E.
A Physically-Based Estimation of Maximum Precipitation over American River Watershed, California.
Journal of Hydrologic Engineering, ASCE, Vol. 16, issue 4, 351-361, 2011.

Study area:
American River Watershed, California



Traditional PMP estimation procedure
Paulhus and Gilman (1953)
HMR49 [Hansen et al. 1977]
HMR51 [Schreiner et al. 1978]

1. Selecting the historical representative storm
2. Moisture maximization in terms of precipitable water
3. Transposition
4. Elevation and barrier adjustment
5. Adjustment for duration and area

Approximations:

1) Surface precipitation taken proportional to the precipitable water;

$$P \propto w_p$$

2) Precipitable water estimated from surface dew point;

$T_{\mathrm{D,\,storm}} \rightarrow w_{p,\,\mathrm{storm}}$

$T_{\mathrm{D,\,max}} \rightarrow w_{p,\,\mathrm{max}}$

Assume a saturated pseudo-adiabatic lapse rate

3) Storm transposition

These approximations were necessary

due to lack of

a regional atmospheric model

and lack of

computer power

to perform the necessary numerical computations within

reasonable time frames.

Heavy Precipitation Event

Southwest Oregon, Northern California, and Western Nevada

December 26, 1996 - January 3, 1997

The California Department of Water Resources' (DWR) 8-station index, an average of eight precipitation gages located along the northern Sierra Nevada between Lake Shasta to the north and the American River to the south, received 28.89 inches of precipitation for the month of December 1996. This ranks as the second wettest month recorded (since 1920). The wettest month ever occurred in December of 1955 when 30.83 inches were observed. Also, when combining December 1996 and January 1997 precipitation, the 47.84 inches that was observed set the record for the wettest back-to-back months. The table below shows the top six December-January combined precipitation totals.

(From NWS California-Nevada RFC)

8-Station Index Wettest Combined December and January (since 1920)

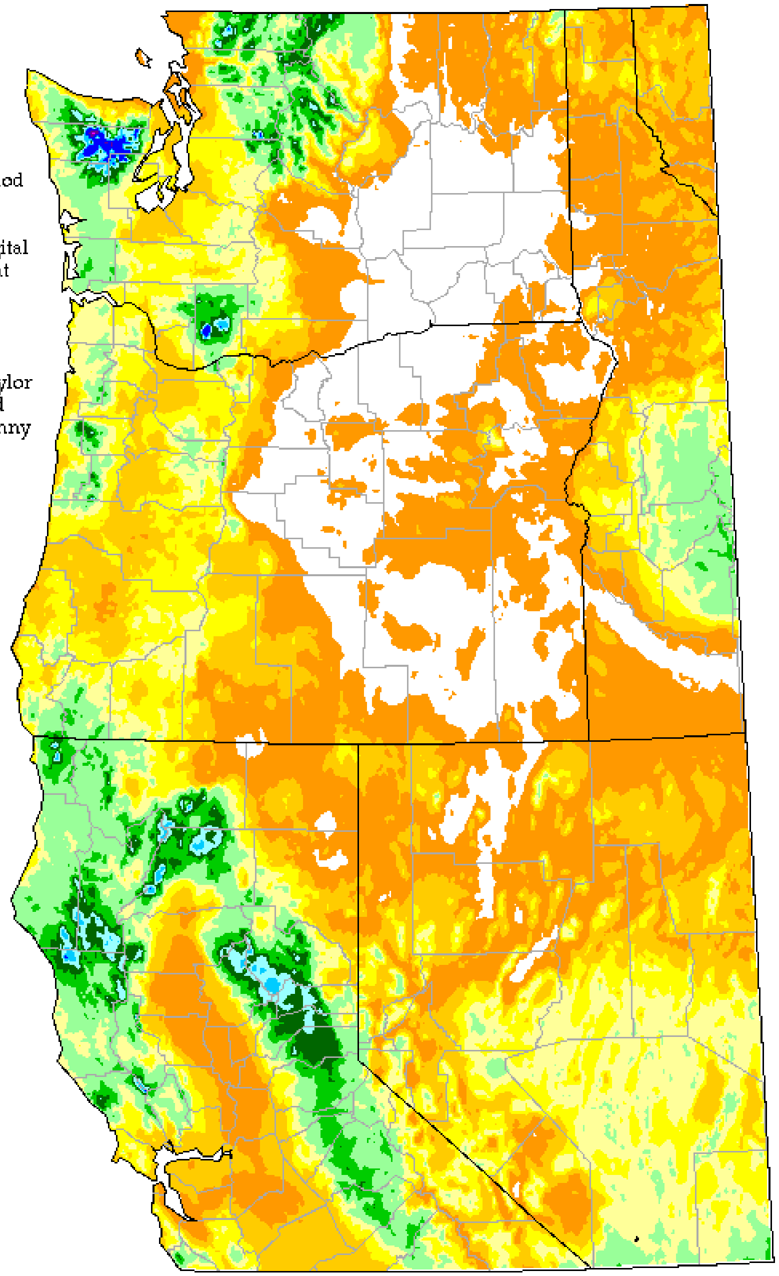
Year	December Total	January Total	Dec and Jan Total
1996-1997	**28.89 Inches**	**18.95 Inches**	**47.84 Inches**
1955-1956	30.83	16.11	46.94
1969-1970	16.86	25.05	41.91
1964-1965	26.71	10.61	37.32
2005-2006	25.80	9.80	35.60
1968-1969	12.15	22.96	35.11

Note: This data is up-to-date as of May 2007.

Total Precipitation, December 29, 1996 - January 3, 1997

Total precipitation for the period December 29, 1996 through January 3, 1997. The PRISM model was used to create a digital coverage using data collected at NOAA cooperative stations, NRCS SNOTEL stations, and USFS/BLM RAWS stations. Modeling was performed by Wayne Gibson and George Taylor of Oregon Climate Service and GIS work was conducted by Jenny Weisberg.

Work was sponsored by U.S. Forest Service, Portland, Oregon



Legend (inches)

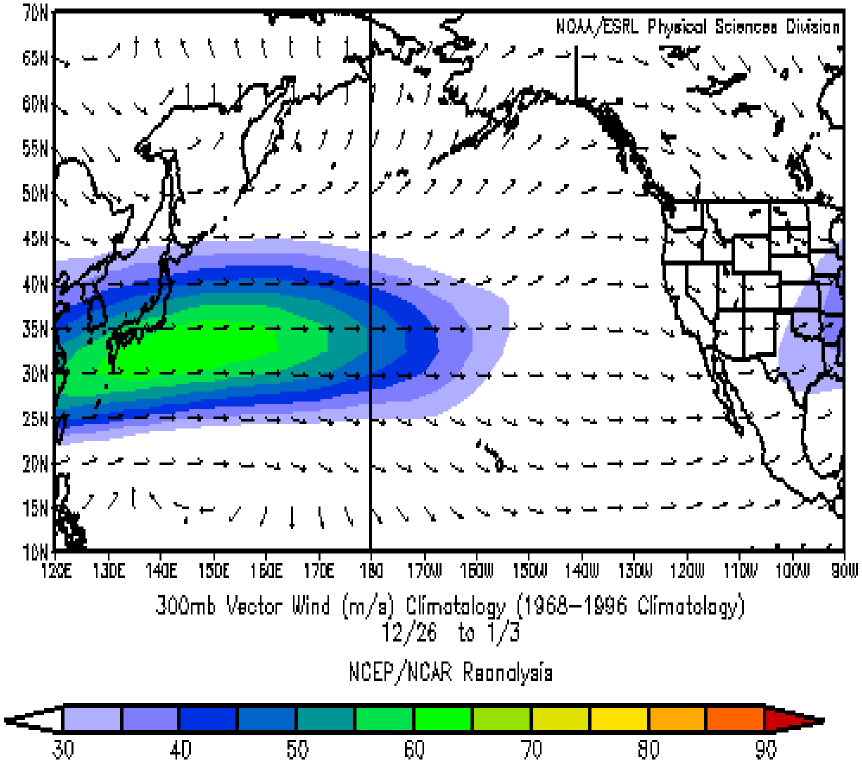
- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 14
- 14 to 18
- 18 to 22
- 22 to 26
- 26 to 30
- 30 to 40
- 40 to 50
- 50 to 60

Oregon Climate Service
541-737-5705

Northern California 6-Day and 9-Day Precipitation Totals Ending January 3, 1997			
Location	***River Basin***	***6-Day Totals 12/29/96-01/03/97 (inches)***	***9-Day Totals 12/26/96-01/03/97 (inches)***
Bucks Lake	Feather	33.28	42.16
La Porte	Feather	30.03	40.04
Blue Canyon	American	27.87	36.34
Auburn Dam Ridge	American	7.25	9.57
Sacramento	American	2.46	3.71

(From NWS California-Nevada RFC)

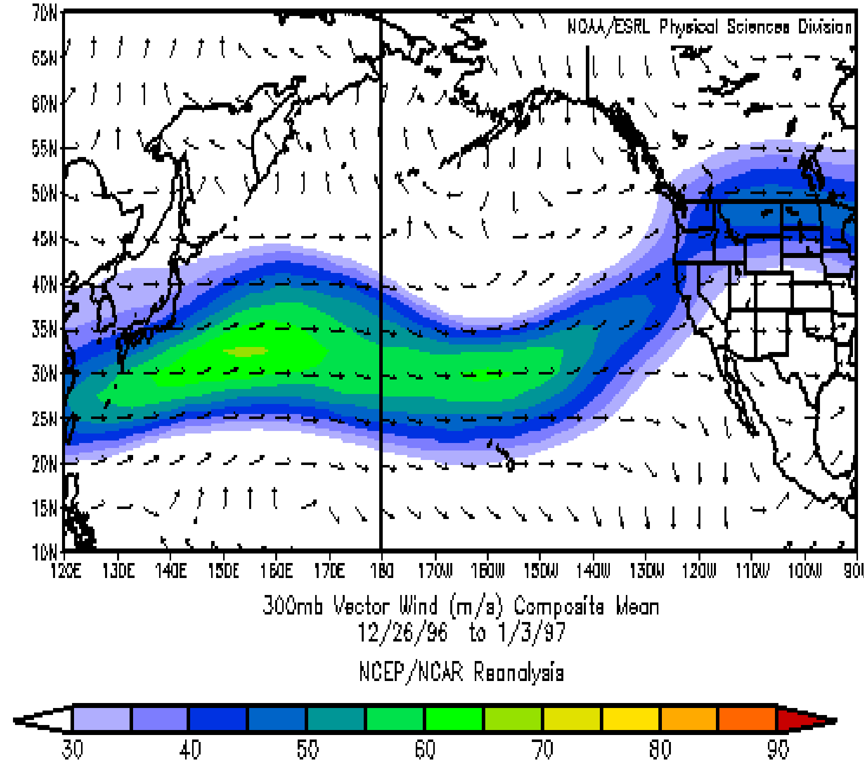
300 mb Wind Vector Climatology (1968 to 1996 data) for December 26 - January 3



The upper jet stream across the Pacific during the late December and early January timeframe is typically strongest from just off the Asian continent eastward to the International Dateline, between 30° and 35° North

(From NWS California-Nevada RFC)

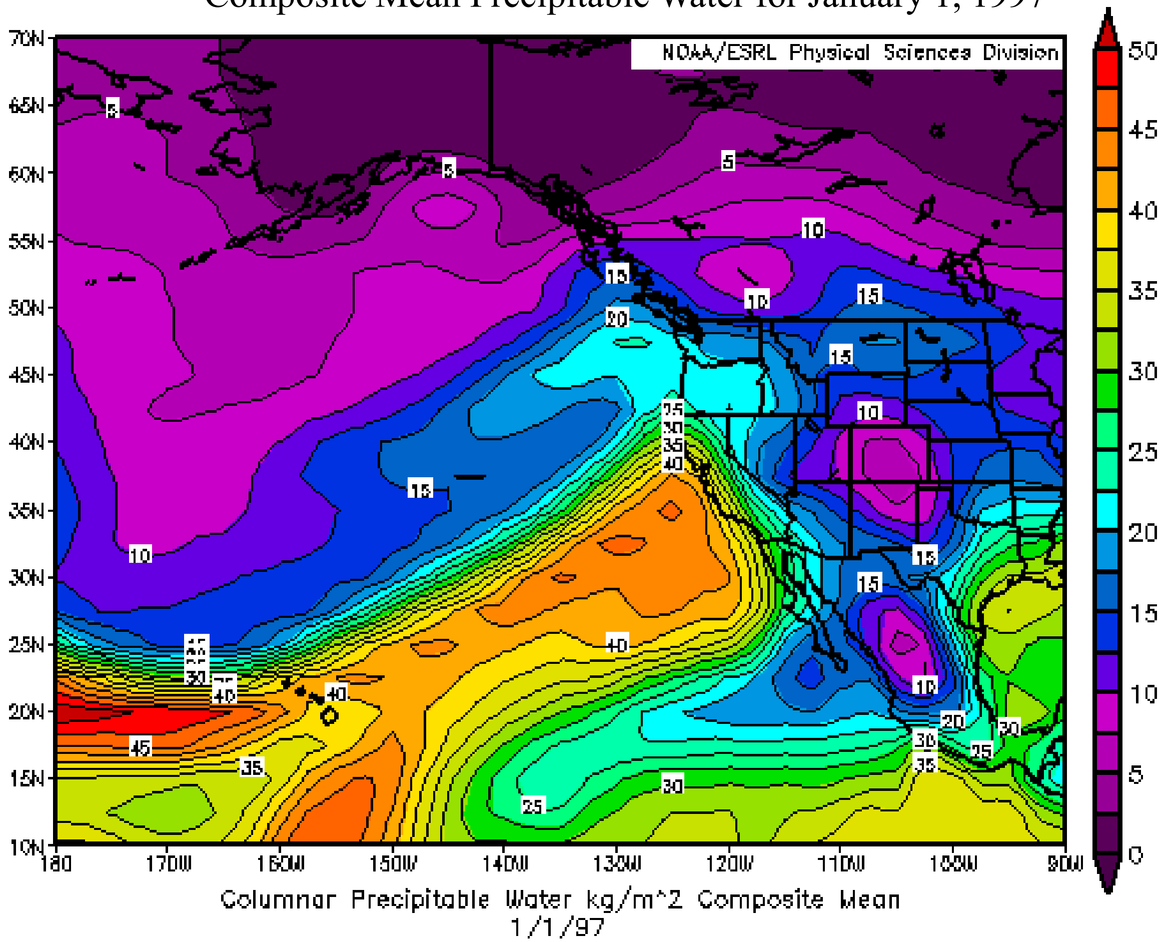
300 mb Wind Vector Analysis for December 26 , 1996–January 3,1997



However, during the December 26, 1996 through January 3, 1997 period, the upper jet stream extended across the eastern Pacific and arched from just north of the Hawaiian Islands toward the Pacific Northwest and northern California

An influx of lower latitude moisture played a key role in the generation of significant precipitation across the region. Two distinct moisture sources were evident on the precipitable water analysis between December 26, 1996 and January 3, 1997. The first source advected eastward from the western Pacific toward the Hawaiian Islands. The second advected northward from near the equator between 150° and 160° West. These two moisture plumes merged near the Hawaiian Islands, and shifted northeast toward the west coast of the United States. Composite daily mean precipitable water values just off the California coast exceeded 1.6 inches (40 mm) and peaked near 1.8 inches (45 mm), as shown in Figure below. Given the tropical origin of the air mass that accompanied these storms, efficient warm rain processes dominated during the event, reducing the snow pack already in place from previous storms (From NWS California-Nevada RFC).

Composite Mean Precipitable Water for January 1, 1997



The 12/26/96 – 1/3/97 event has shown that:

1) The phase of the precipitation is important (warm rain on the already-existing snow pack over Sierras leading to substantial snowmelt and consequent high flows);

2) The wind field with respect to its trajectory and speeds is important to the moisture inflow into the target watershed.

Evolution of a storm over a region
may be considered as
an initial-boundary value problem in mathematical physics.

Within this framework the evolution of a historical severe storm over a target watershed can be simulated by means of a numerical atmospheric model that solves the pertinent atmospheric dynamics and thermodynamics under the appropriate initial and boundary conditions (ICs and BCs).

These ICs and BCs may be provided by historical NCEP/NCAR Re-analysis data at the coarse 2.5^{o} grid resolution over the model domain for 1948-present period.

The numerical atmospheric model for

American River Watershed

is taken as

MM5 (Fifth Generation Mesoscale Model)

from NCAR (National Center for Atmospheric Research) and Penn State Univ.

because,

MM5 is a nonhydrostatic model which can be

downscaled even to 1km spatial resolution,

which makes it very desirable for downscaling

coarse-resolution historical atmospheric data

to the scale of American River Watershed,

and be able to capture

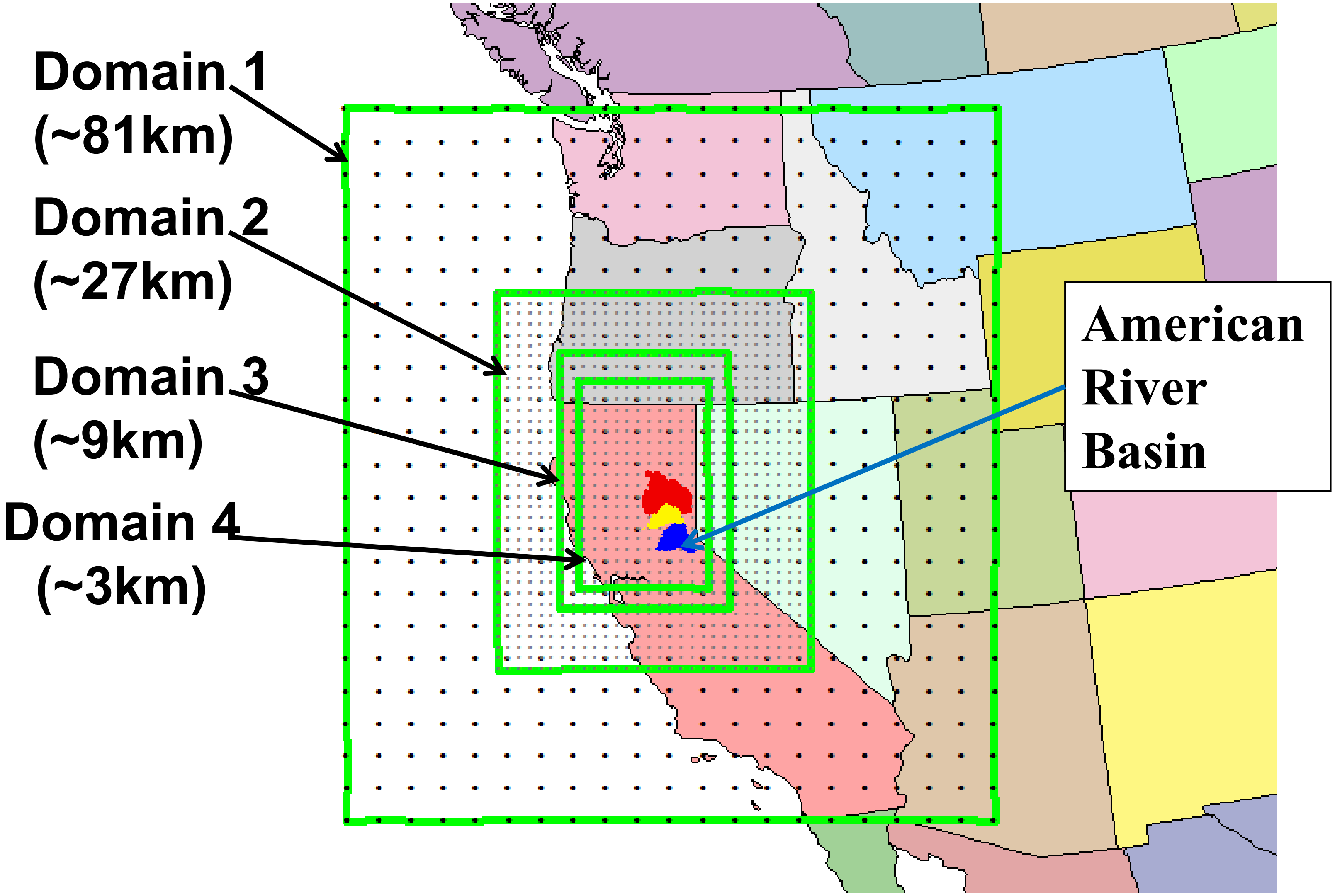
the impact of

steep topography and land surface/land use conditions of

American River Watershed on the local atmospheric conditions.

Model nesting domains

Lambert Conformal Conic Projection



Configuring the atmospheric model

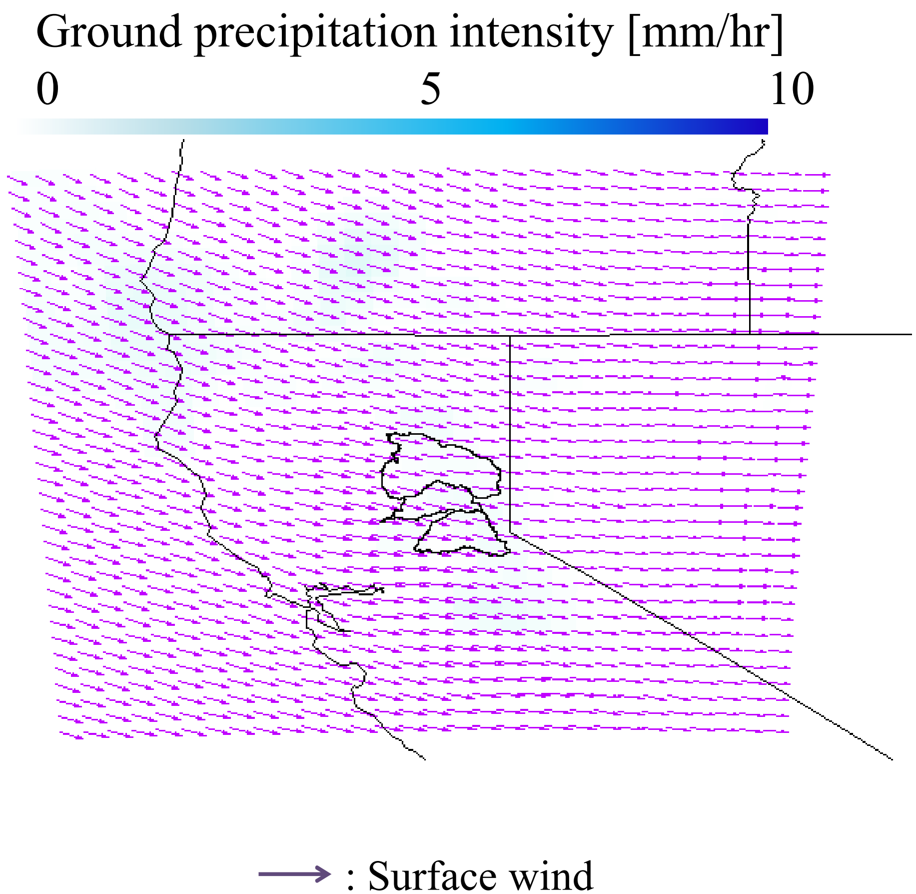
	Cumulus Parameterization	Cloud Microphysics	PBL Schemes
Case1	Kain-Fritsch 2	Mixed-Phase (Reisner1)	MRF
Case2	Grell	Mixed-Phase (Reisner1)	MRF
Case3	Kain-Fritsch 2	Reisner graupel (Reisner2)	MRF
Case4	Grell	Reisner graupel (Reisner2)	MRF
Case5	Kain-Fritsch 2	Mixed-Phase (Reisner1)	Gayno-Seaman
Case6	Grell	Mixed-Phase (Reisner1)	Gayno-Seaman
Case7	Kain-Fritsch 2	Reisner graupel (Reisner2)	Gayno-Seaman
Case8	Grell	Reisner graupel (Reisner2)	Gayno-Seaman

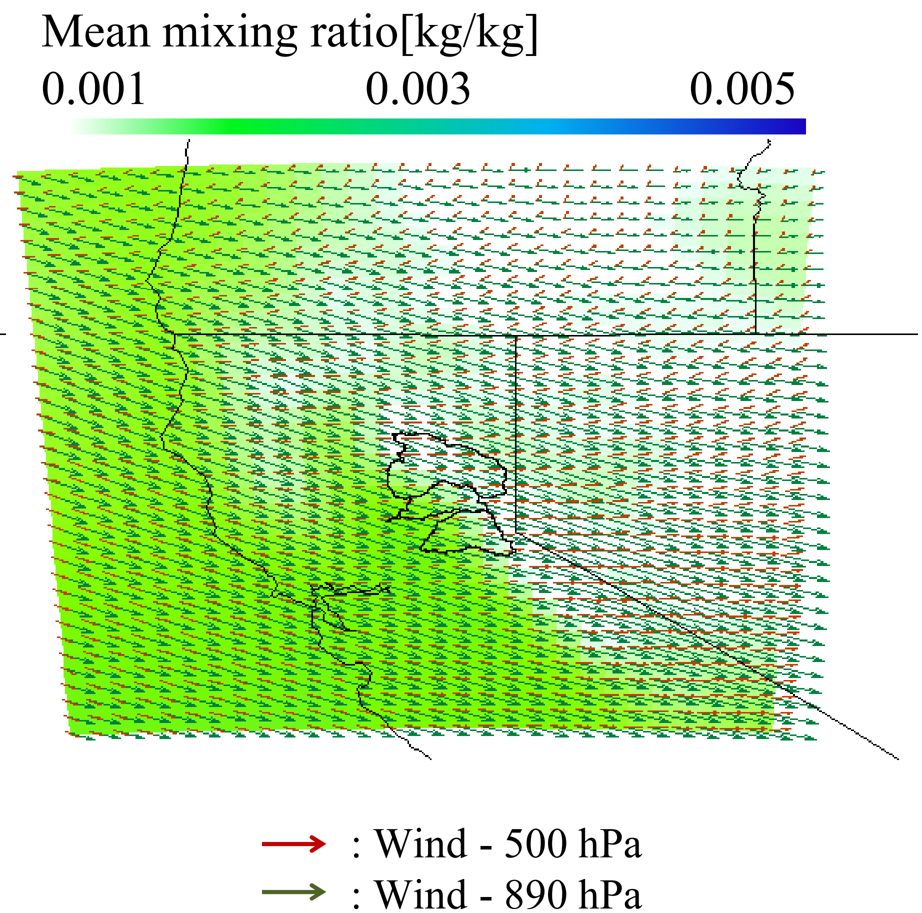
Evaluation results:

Monthly Comparison		**PRISM**	Case-1	Case-2	**Case-3**	Case-4	Case-5	Case-6	Case-7	Case-8
Dec	Precipitation (in)	**27.70**	27.62	28.57	**27.43**	28.52	27.35	27.62	27.11	27.81
	Dif. (%)	**-**	-0.27	3.15	**-0.99**	2.94	-1.28	-0.30	-2.14	0.40
Jan	Precipitation (in)	**23.27**	26.95	27.41	**25.23**	25.94	27.68	28.26	26.86	26.81
	Dif. (%)	**-**	15.84	17.81	**8.43**	11.48	18.96	21.48	15.44	15.23

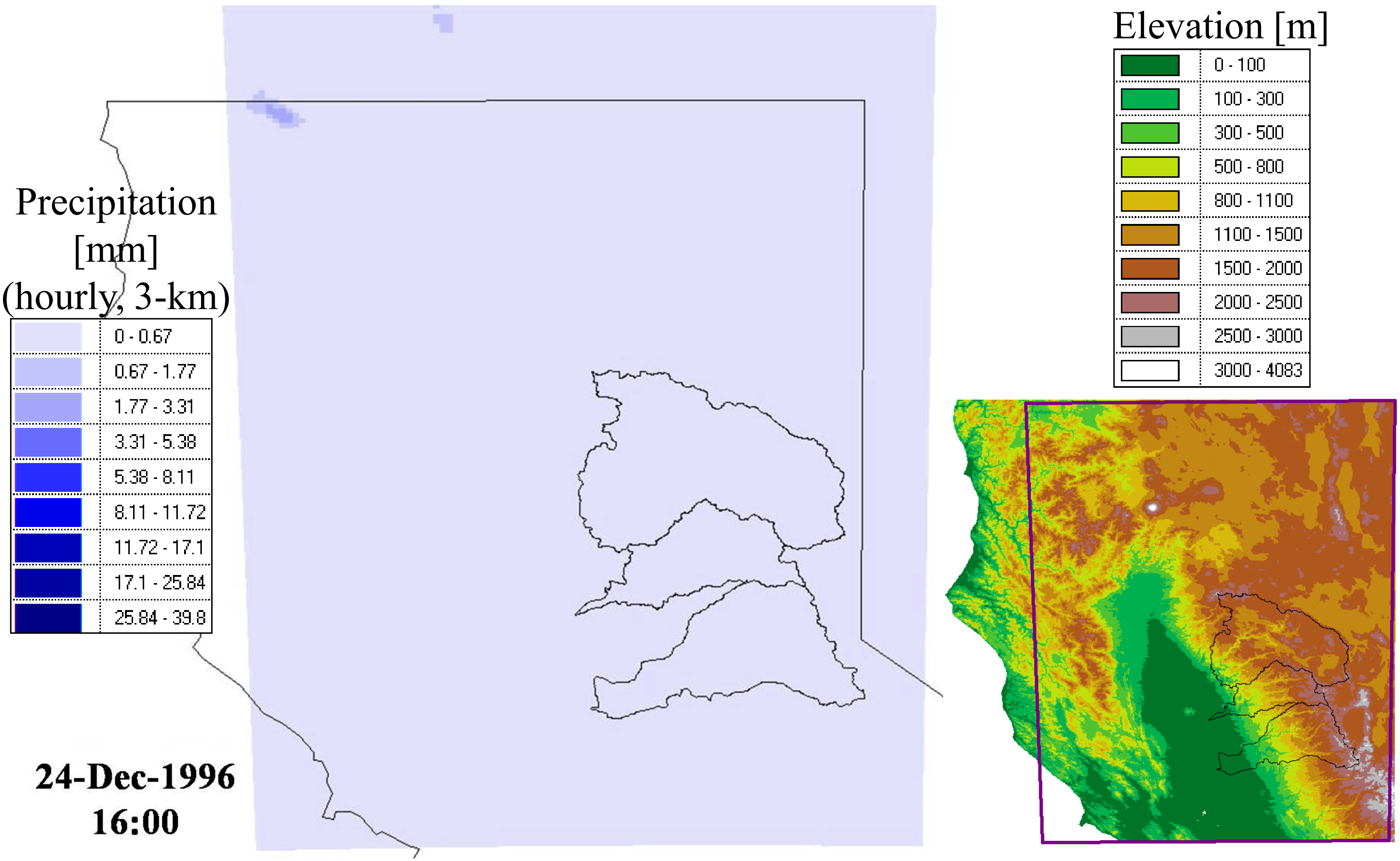
Example output of the numerical atmospheric model at 27km grid

1996-12-24 ~ 1997-01-03 event



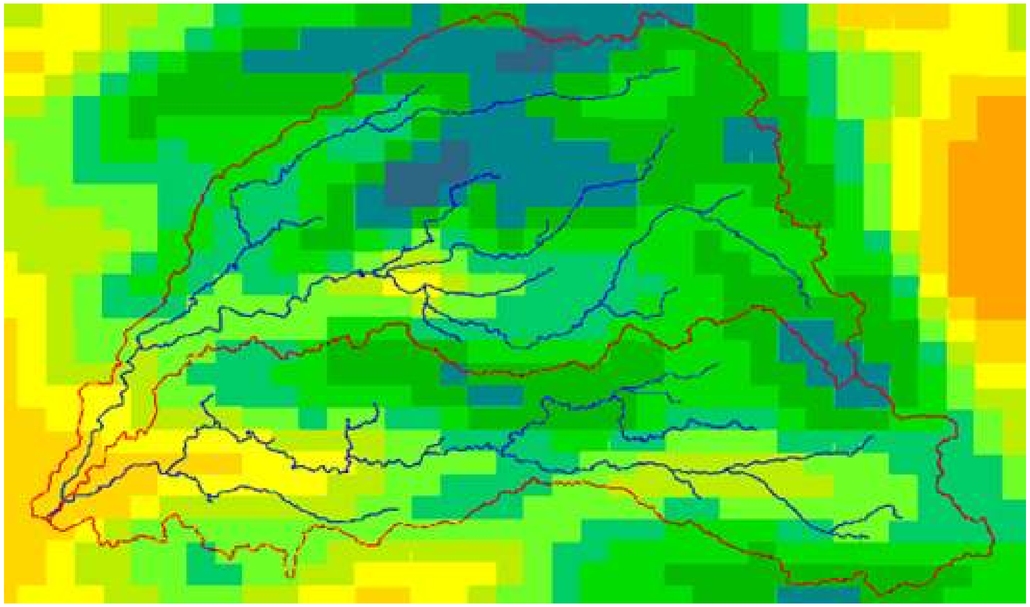


Precipitation on ground surface simulated by MM5 at 3km grid during December 24, 1996 – January 3, 1997

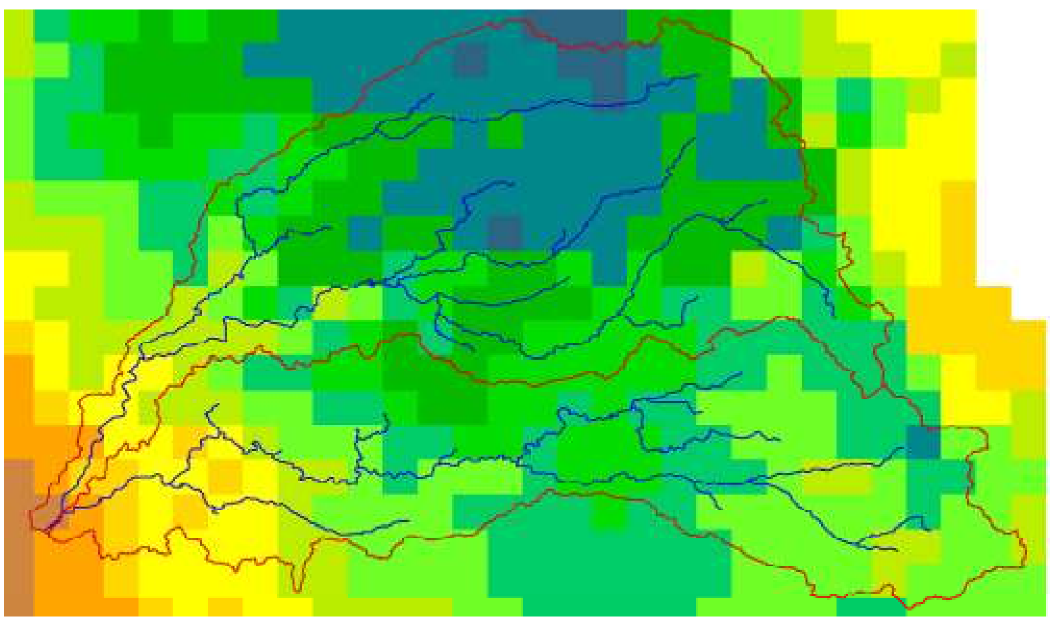


December 2006

Reconstructed (Dec 2006)



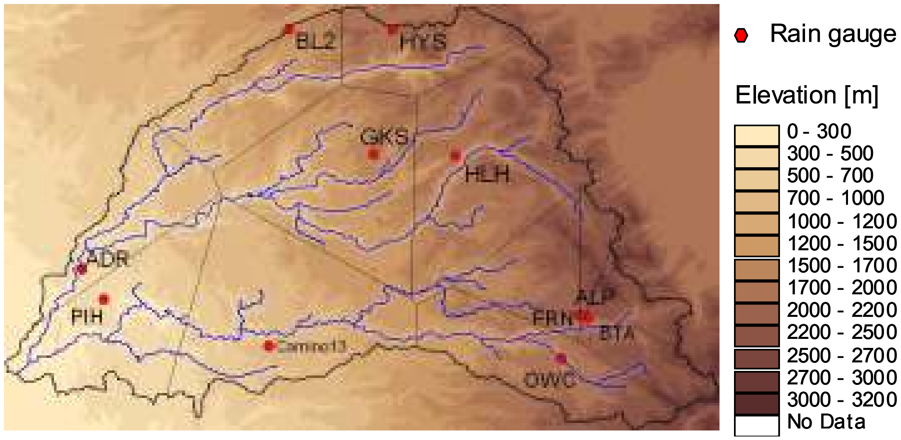
PRISM (Dec 2006)

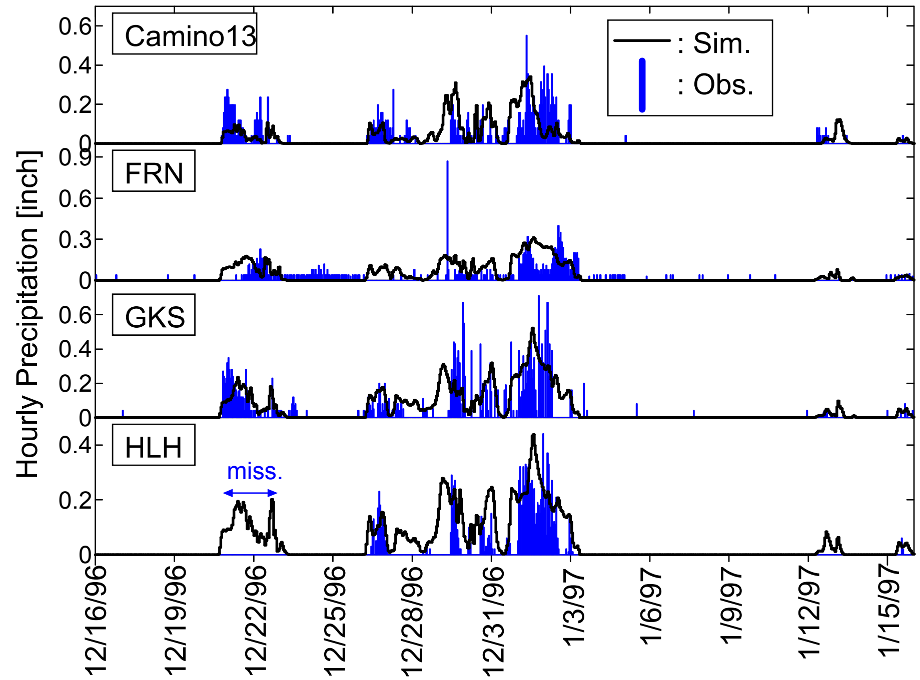


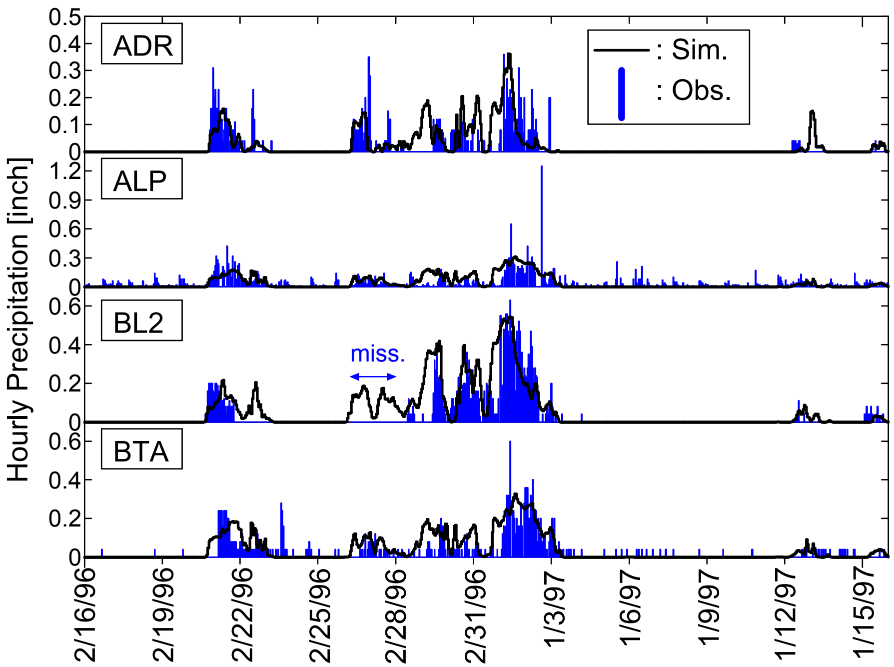
(mm)

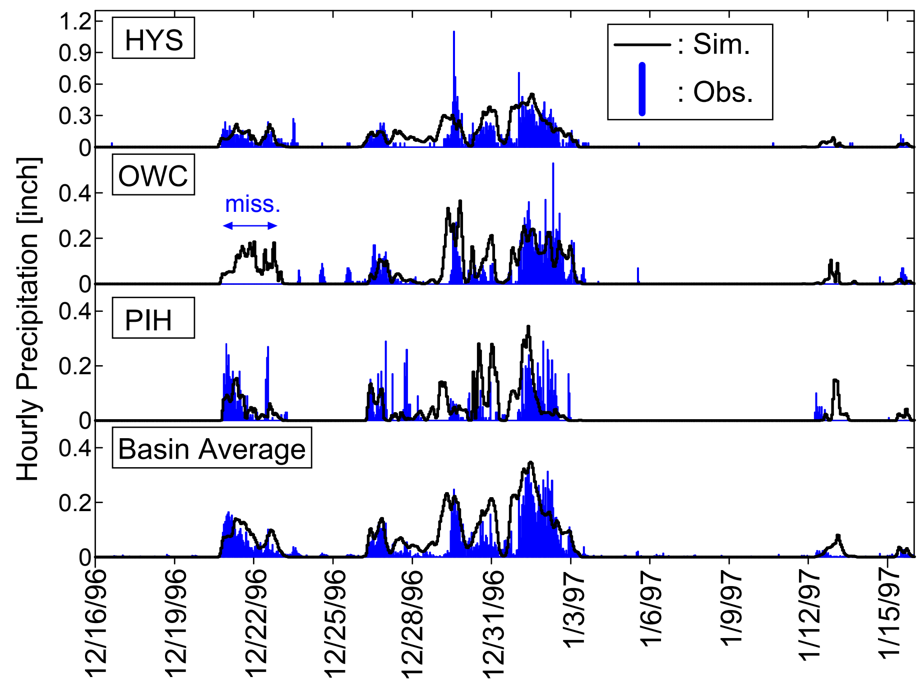
127 - 178
178 - 254
254 - 330
330 - 406
406 - 483
483 - 584
584 - 686
686 - 787
787 - 914
914 - 1067
1067 - 1245
1245 - 1397

Model validation at point locations during the storm event

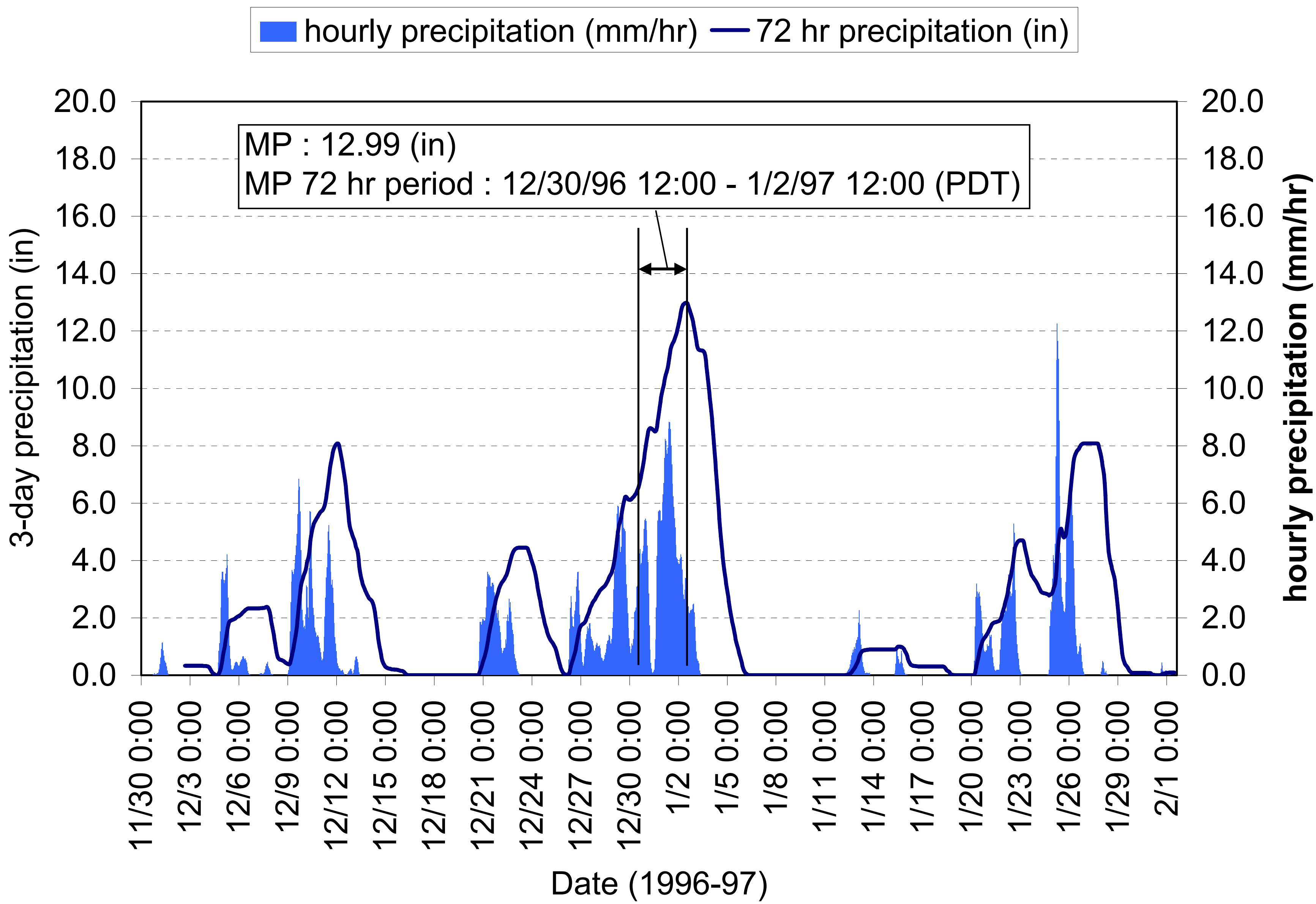




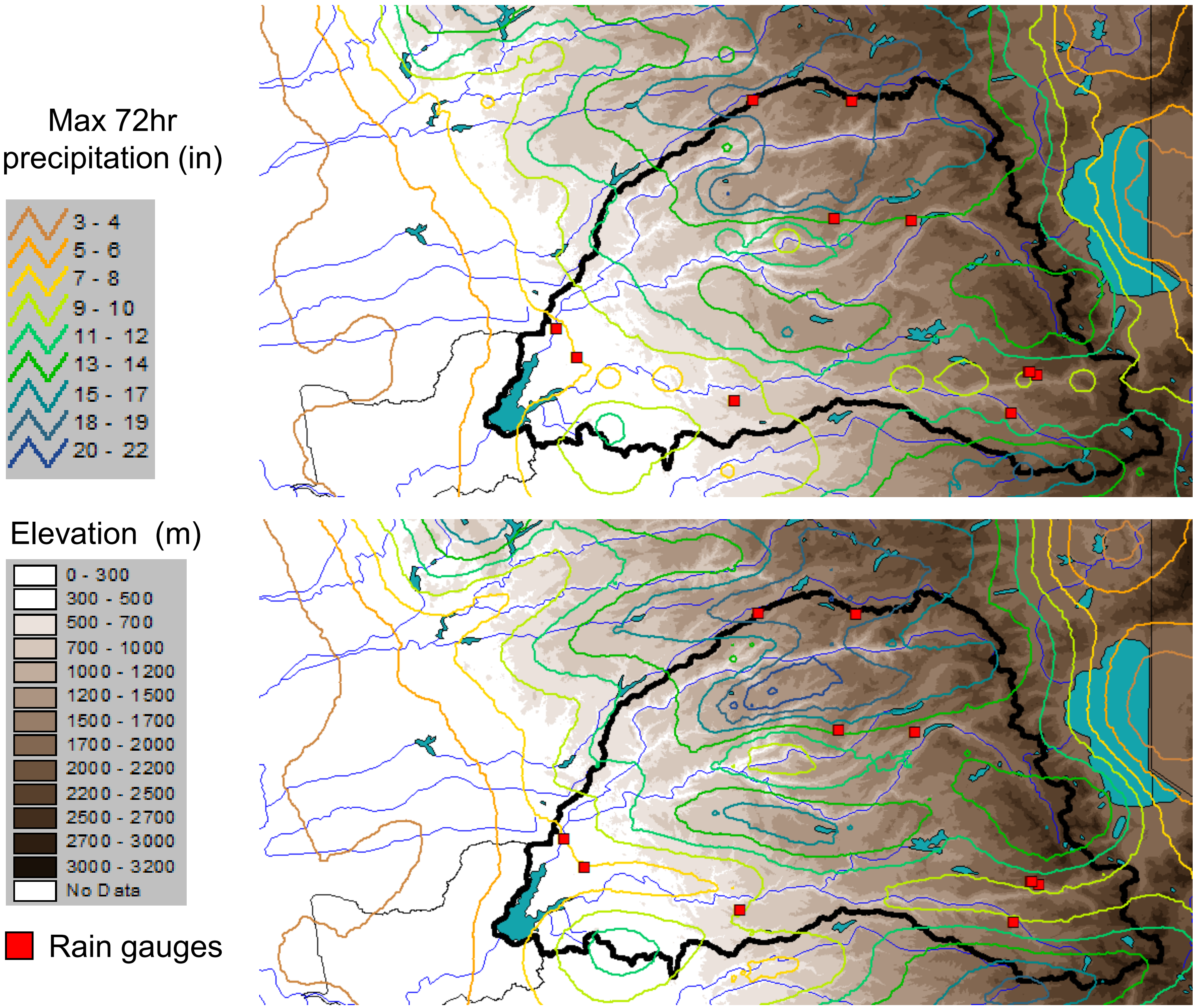




Hourly Basin-averaged Precipitation in the American River watershed and its 72-hour Moving Summation during December 1996 - January 1997 2-months period



72 hr historical MP vs. topography



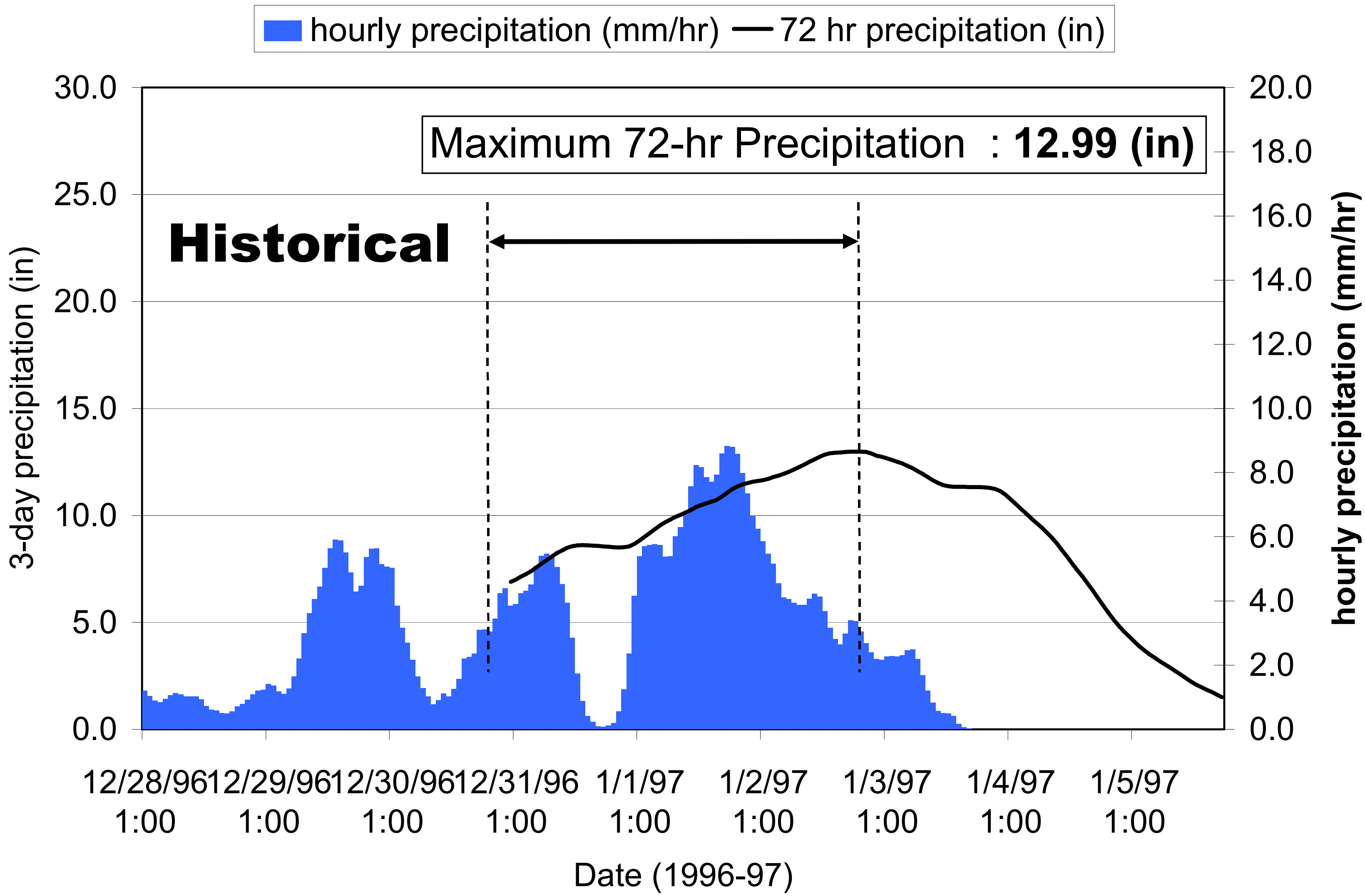
9km resolution

3km resolution

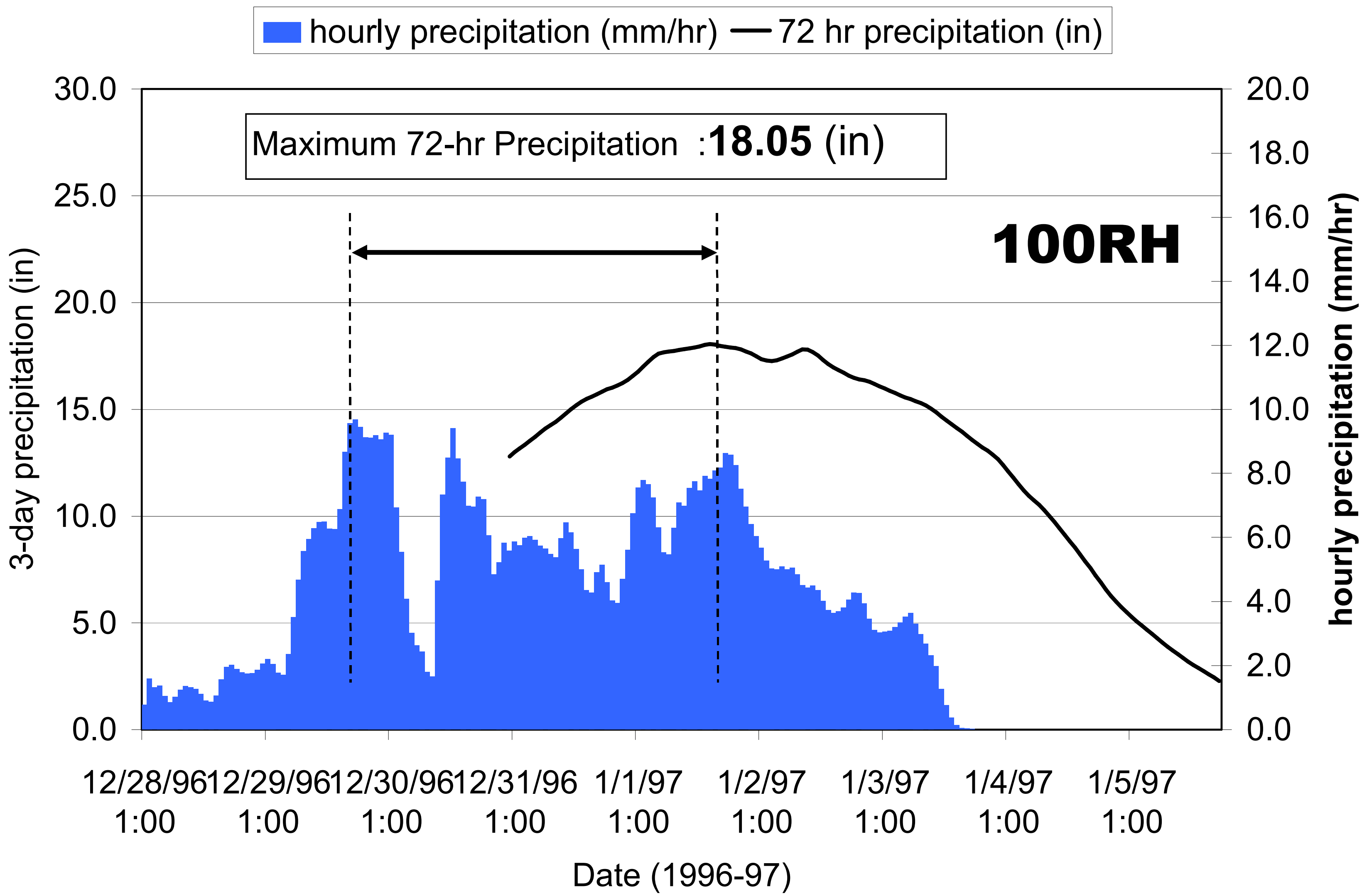
Maximizing Basin-Average Precipitation for 72-hours duration over ARW

1) Maximize the atmospheric moisture inflow to the model domain through the model outer domain boundary;
2) Search for the optimal trajectory of the wind field toward the target watershed by moving the atmospheric river with respect to only latitude along the model outer boundary in this preliminary study;
3) Search for the optimal wind speeds along the model outer boundary (not done in this preliminary study);
4) Combine the optimal moisture and wind conditions;
5) Repeat the exercise for all the historically-recorded severe storms over California for the 72 hours duration.

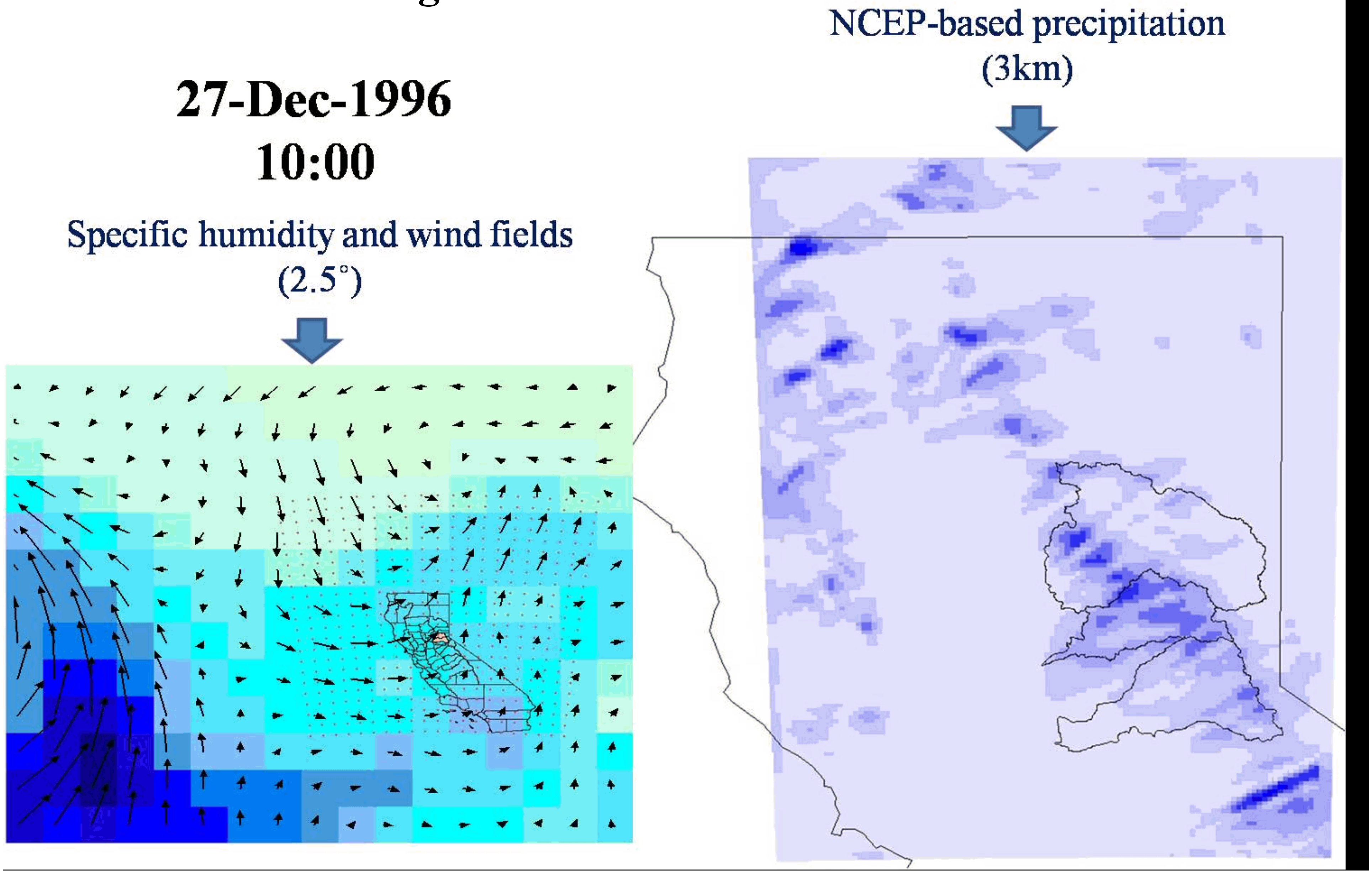
Reconstructed historical storm event



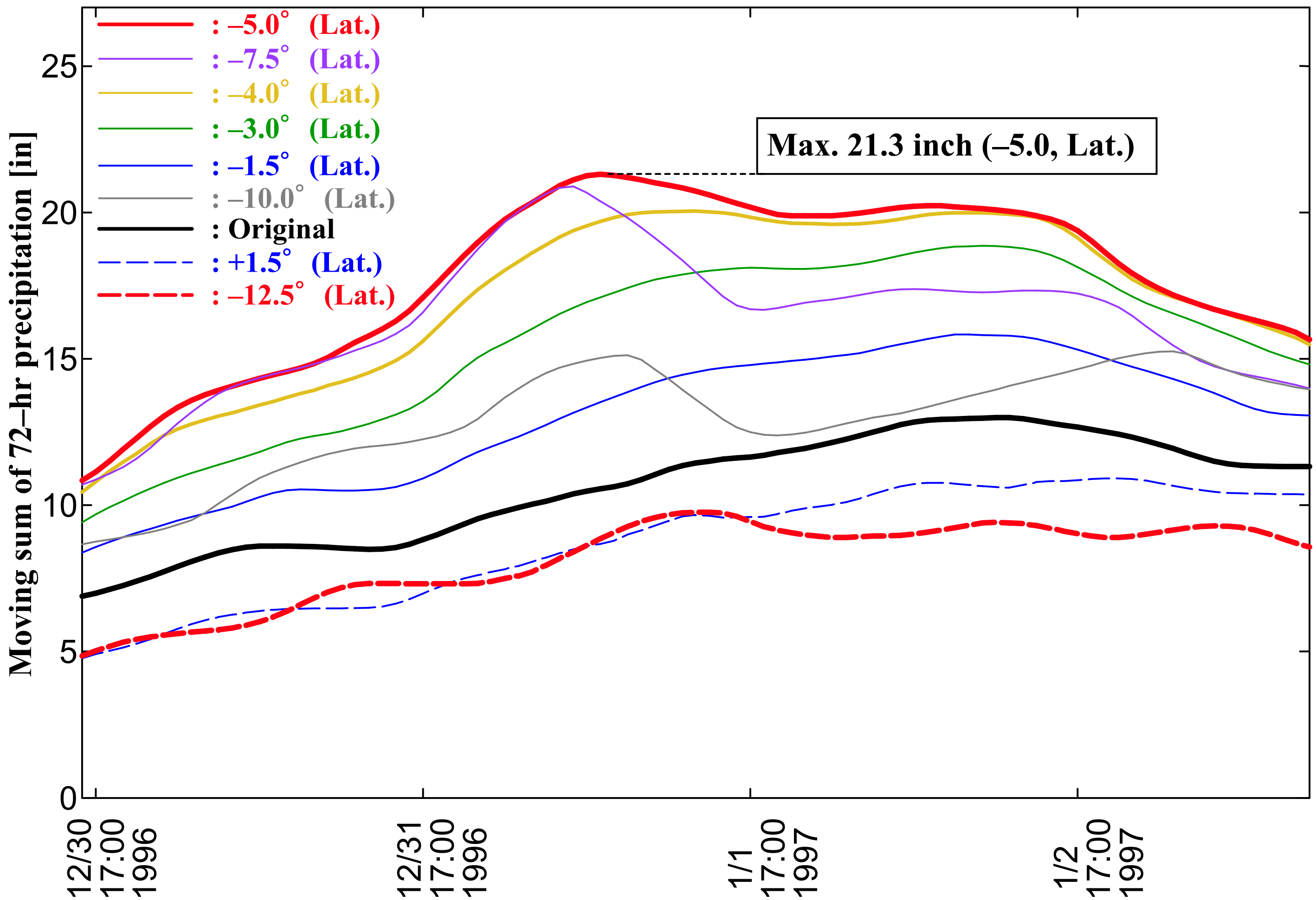
Maximization by relative humidity in the boundary conditions



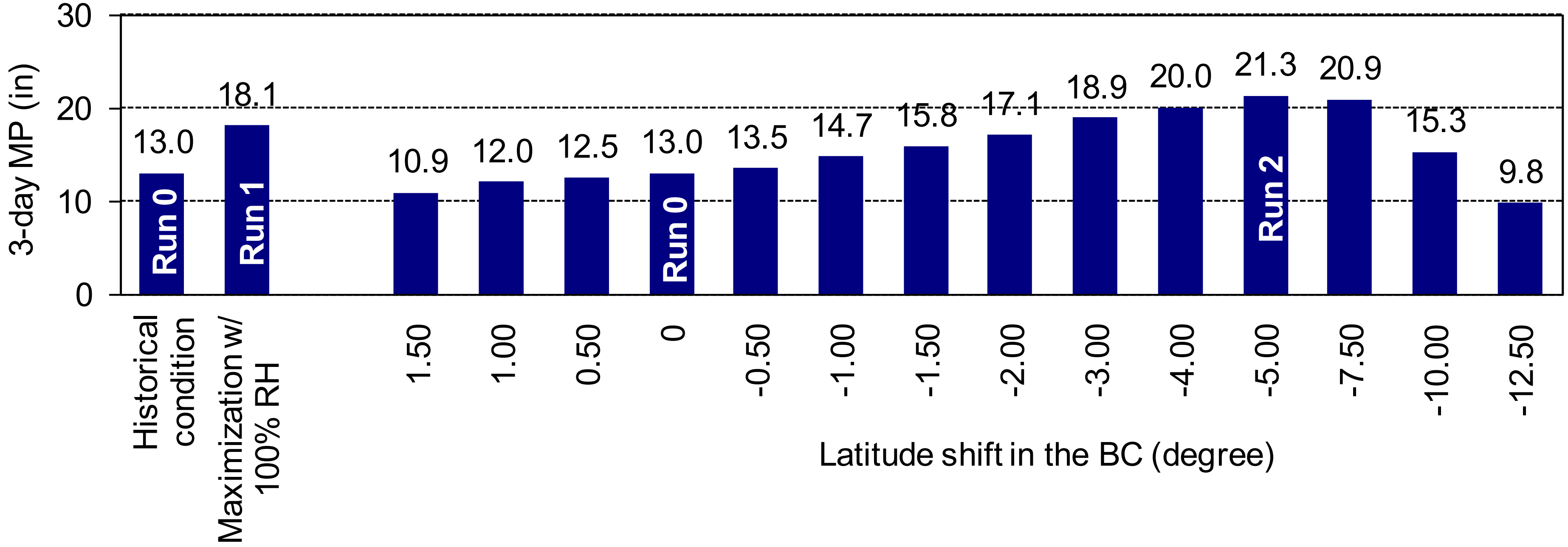
Moisture (vertical summation of specific humidity) and wind (at 915 mb) fields around the Pacific Northwest and California during the 96-97 historical storm event



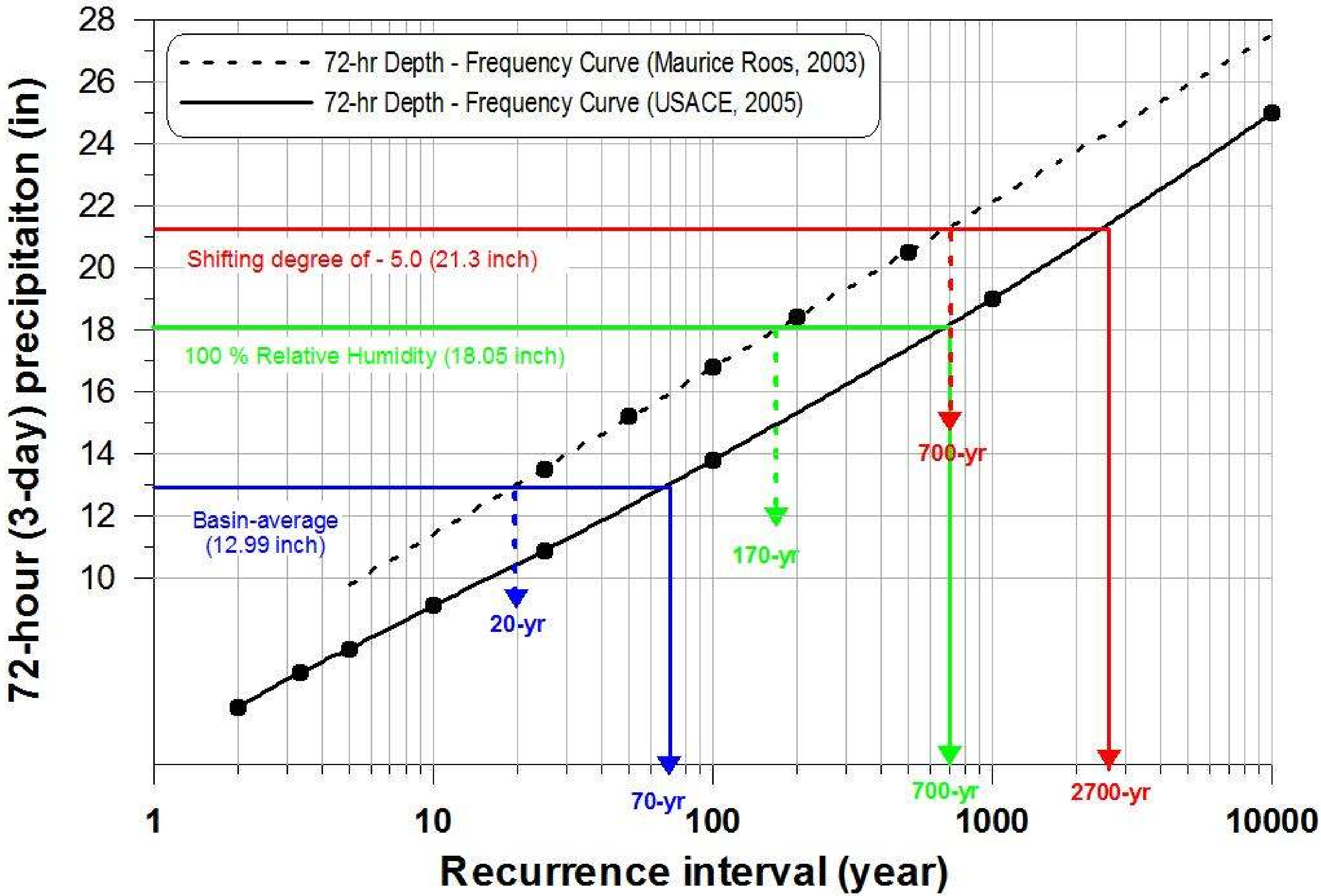
Consecutive 72-hr Moving Summation of Precipitation for each Shifting Condition from +1.5 degree to -12.5 degree in latitude



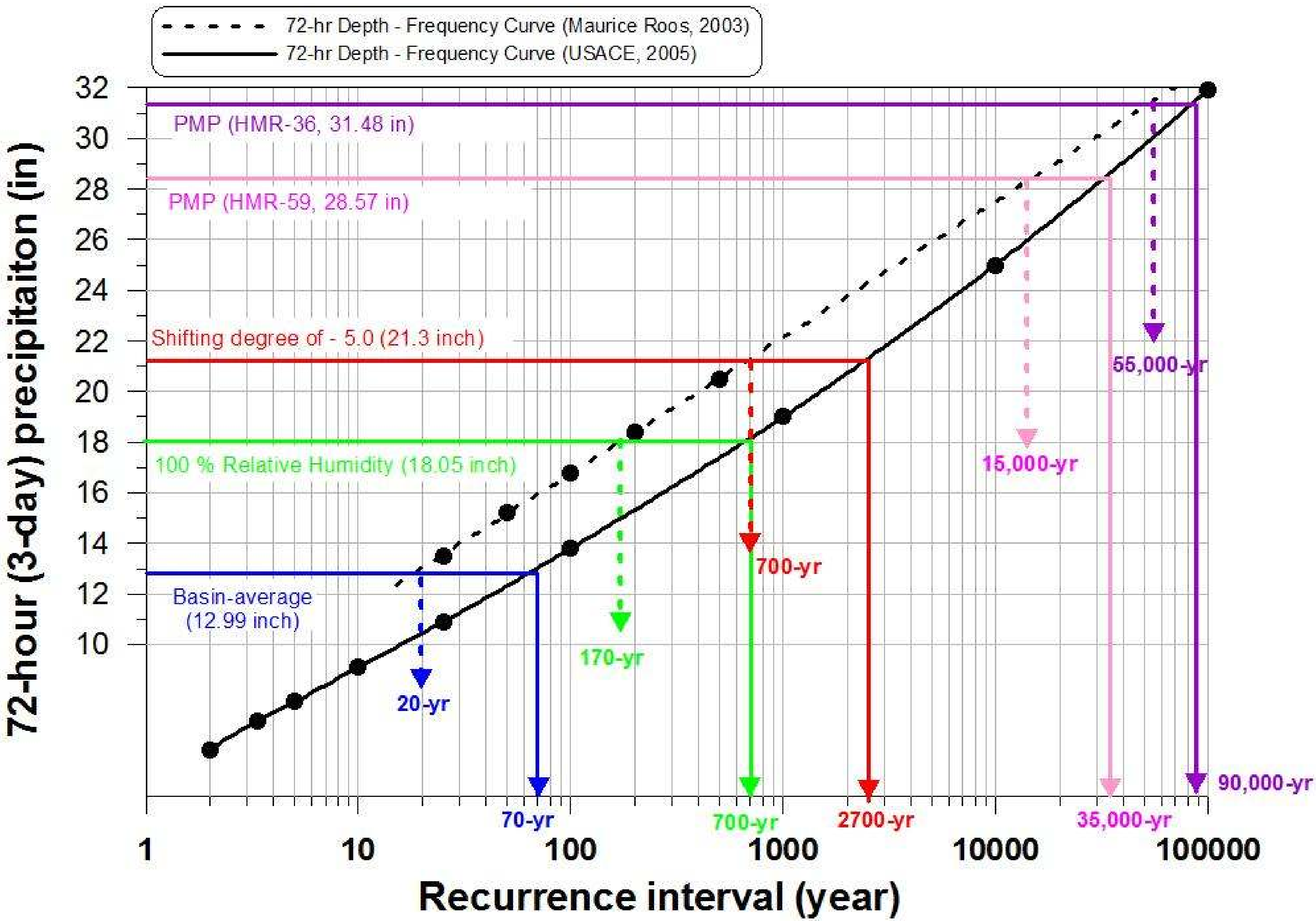
Historical and maximized 72-hour precipitation of American River Watershed during the December 26, 1996 – January 3, 1997 event



Estimated 72-hour precipitation recurrence intervals Corresponding to [maximizing relative humidity at OB] and [spatially-shifting the atmospheric river at OB]



Comparisons of the estimated MP values based on 1996-1997 event against existing PMP values



Repeat the whole above exercise for various durations (6 hours; 12 hours; 24 hours; 48 hours; 72 hours) over ARW

Conclusions

This preliminary study demonstrates how the boundary conditions of a numerical atmospheric model can be modified in order to estimate the maximum 72-hour basin-averaged precipitation at American River Watershed.

Preliminary estimate of maximized 72-hour basin-averaged precipitation over ARW based on Dec, 1996 – Jan,1997 event :

541 mm (21.30 inches)

Existing PMP values:

800 mm (31.48 inches) (HMR36, 1961),

726 mm (28.57 inches) (HMR59, 1999)

During a maximum precipitation event not only the maximum precipitation depth but also

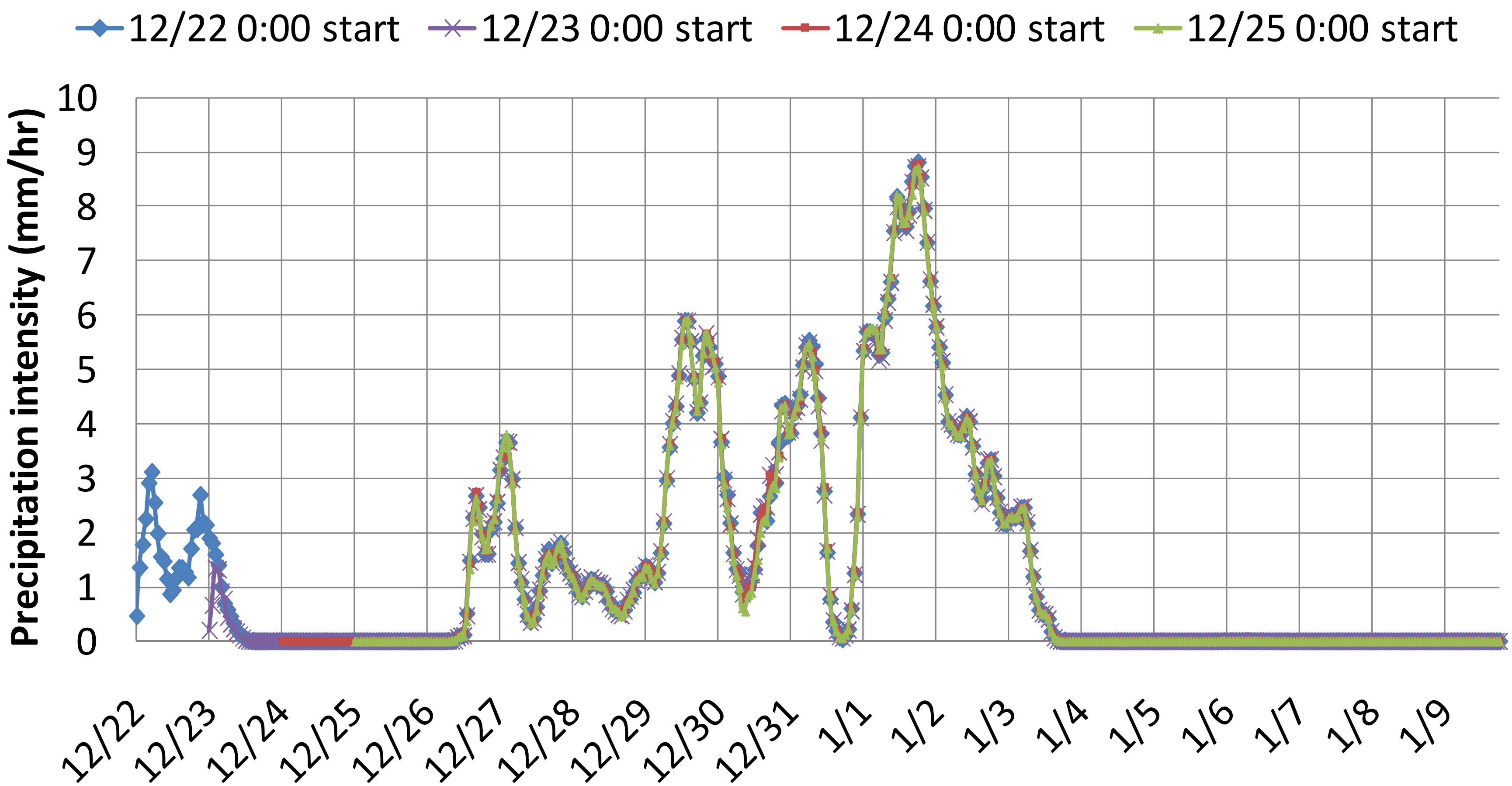
a) information on the variation of the precipitation rate both with respect to time and with respect to spatial location over the target watershed;
b) information on the other atmospheric variables that accompany the maximum precipitation event,

will be very useful during the subsequent hydrologic modeling for the PMF.

A physically-based, spatially-distributed watershed hydrology model that is coupled to the numerical atmospheric model (such as MM5, used in the reported study) of the maximum precipitation event, can then utilize not only the precipitation information but also wind, air temperature, humidity and radiation information in time and space in order to simulate the corresponding flood event.

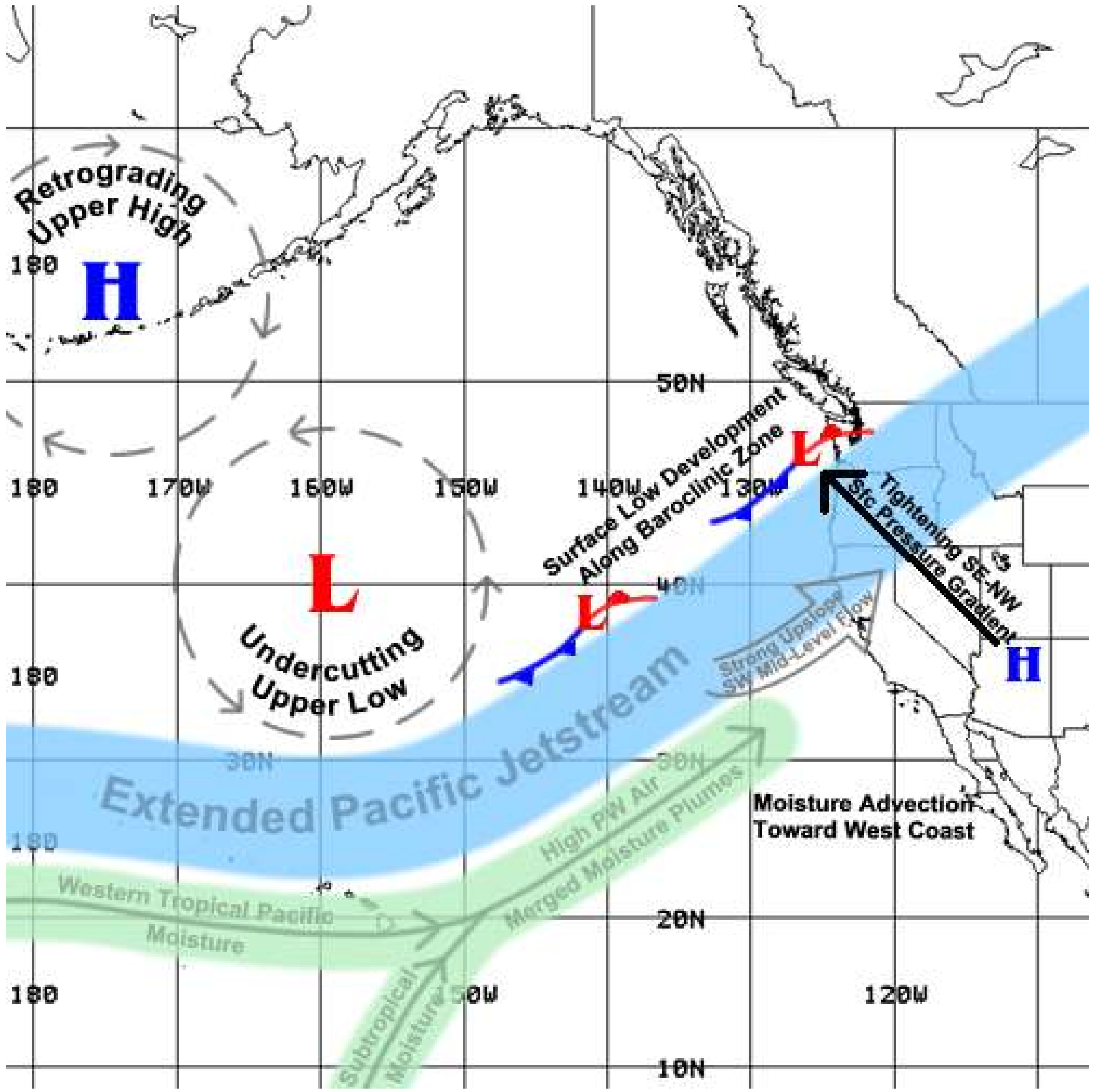
Thank You

Effect of initial condition to the precipitation model results



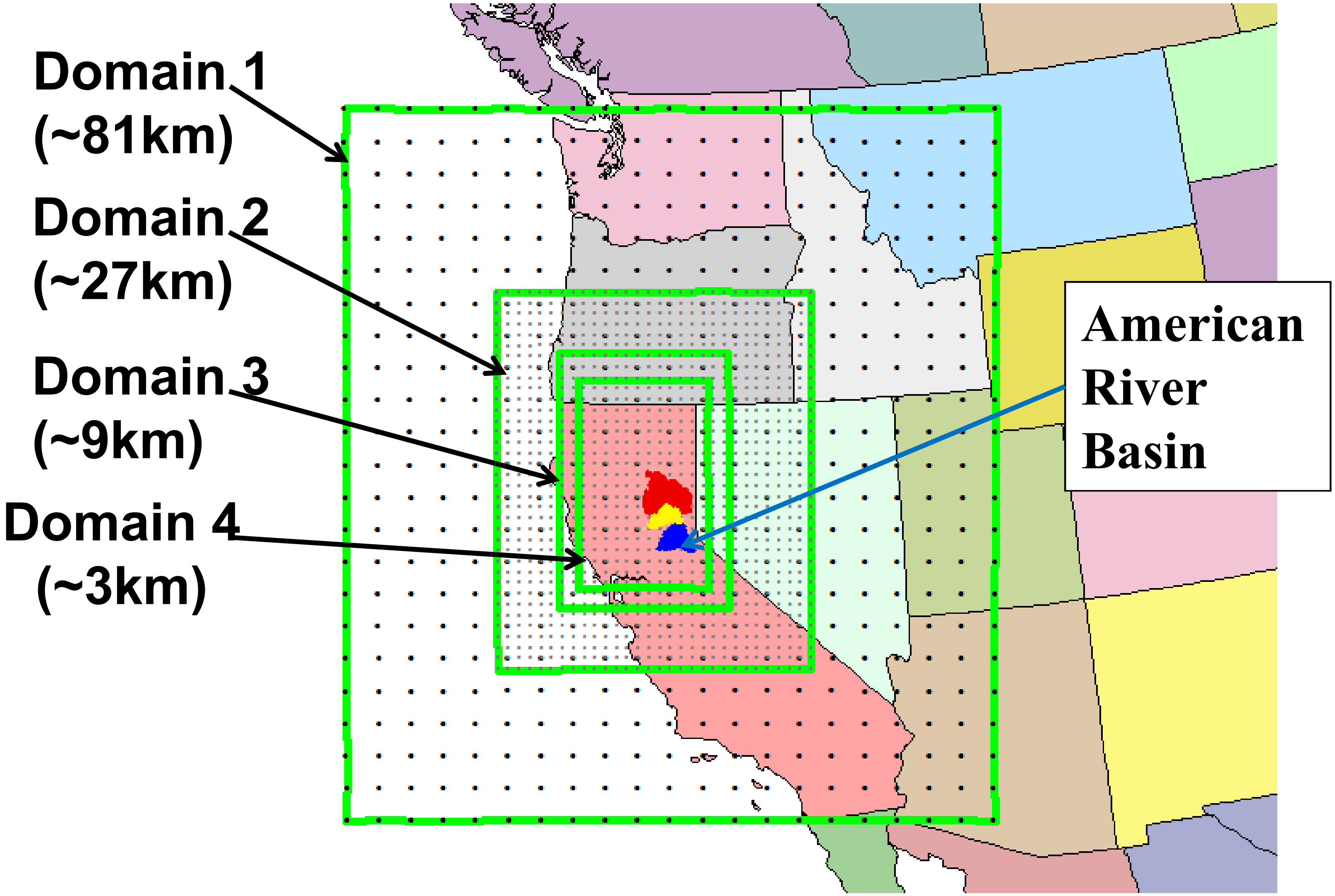
The regional numerical weather modeling (meso scale modeling) may be regarded as an initial- boundary value problem.

Synoptic pattern of the December 26, 1996 - January 3, 1997 storms



Model nesting domains

Lambert Conformal Conic Projection



Moisture Maximization

(Traditional PMP estimation procedure, Schreiner & Riedel, 1978 (HMR51))

$$P_{\max} = \frac{w_{p,\max}}{w_{p,storm}} P_{storm}$$

P = surface precipitation
w_p = precipitable water
storm = selected historical storm value
max = value corresponding to observed $T_{d\max}$

Precipitable water is usually estimated from observed surface dew point temperature