Climate Change, Extreme Precipitation, and Atmospheric Rivers

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Desert Research Institute

Reno NV

Workshop on
Climate Change, Extreme Weather, and Central Valley Floods
California Department of Water Resources
West Sacramento, CA 2012 Feb 14

Western Regional
Climate Center

Extremes matter

Societal physical and behavioral infrastructure are built around:

- **Central tendencies - the many**
  - **High probability / low consequence events**
- **Distribution tails - the few**
  - **Low probability / high consequence events**

Huge societal investments ($B, $$B, $$$B) to withstand rare events

Where do we obtain these probabilities?

- **Pertinent decisions are about the future: hence, these are <u>forecasts</u>**
- **The commonsense assumption: Past is Prologue**
  - **The past as a reliable guide to the future**
  - **Past statistics = Future statistics**
- **The past (as established "fact") has built-in credibility as a forecast**
  - **Automatic, relatively painless buy-in**
- **Climate stationarity is implicit in this assumption**

Two major audiences to satisfy:

- **Scientific**
  - **What is intellectually defensible, accurate, correct?**

- **Societal**
  - **Acceptance by the engineering profession**
    - **Methodologies that are understandable, transparent, explainable, etc**
      - **Practical and implementable**
  - **Acceptance by the planning community**
    - **Huge $$$ at stake in building for extremes**
  - **Acceptance by political process**

For both audiences

- **For a stationary climate**
  - **Reasonably constrained range of options**
  - **Considerable experience base to work from**
- **For a nonstationary climate**
  - **Many more possible options to choose from**
    - **Lots of ways to “be nonstationary”**
  - **Experience base very limited**

Not “just” a science problem, but a joint science-society problem

Intensity - Duration - Frequency (IDF) Curves :Rates
Depth - Duration - Frequency (DDF) Curves :Sums

What is our expectation of

1) How much, 2) Over what time interval, 3) How often ?

Much, much scrutiny
Very widely used
Critical for infrastructure design
Scientific, legal, financial underpinnings

These and other climatic extremes built into
building codes, engineering requirements, legal stipulations, others.

NOAA's National Weather Service

Hydrometeorological Design Studies Center

Precipitation Frequency Data Server (PFDS)

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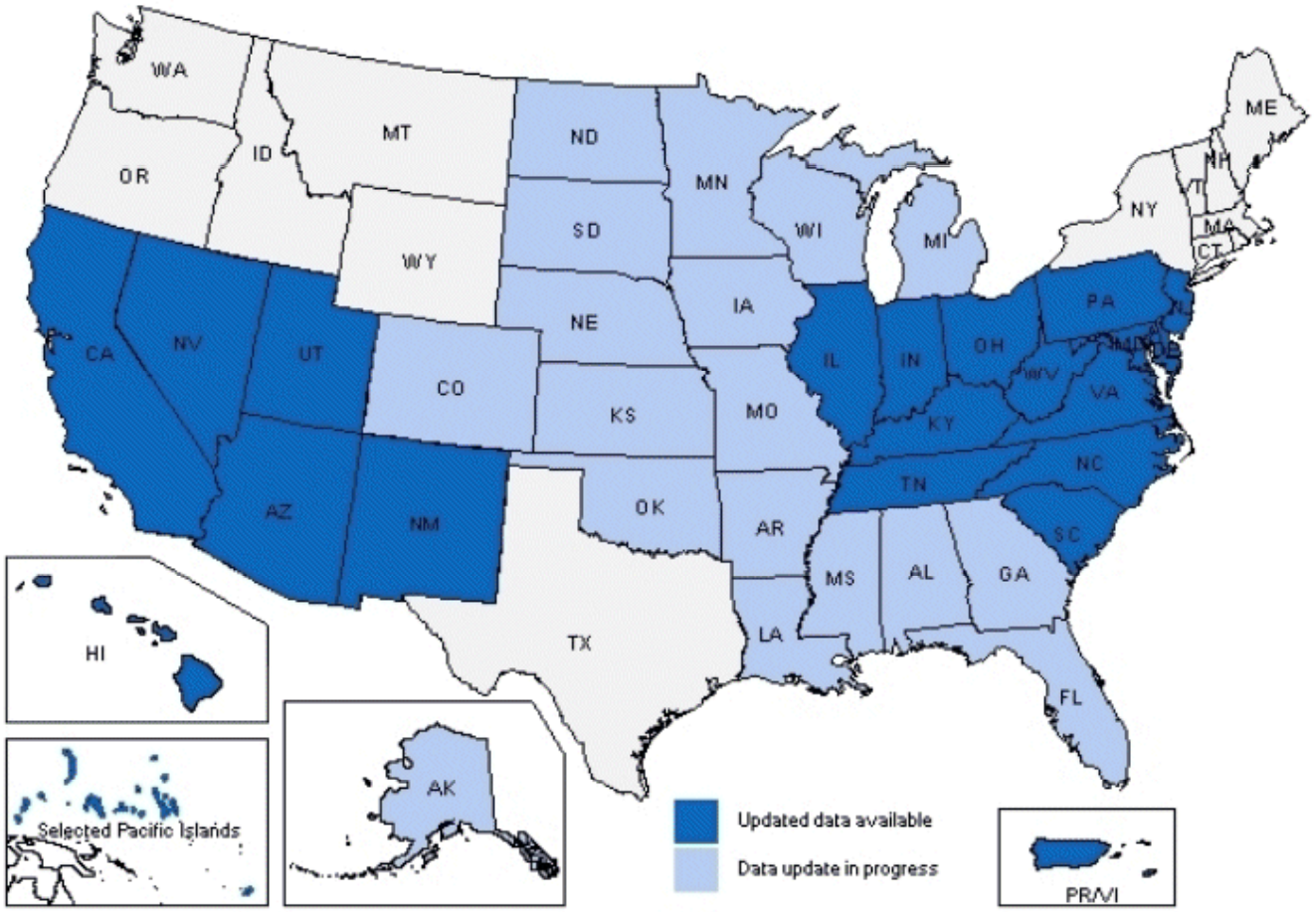
USA.gov Government Made Easy

NEW! Precipitation frequency estimates for California published

State: Choose a state (or click map) Load



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NOAA Atlas 2 Precipitation Frequency Estimates in GIS Compatible Formats

Note: Effective August 6, 2003, NOAA Atlas 2 has been superceded by NOAA Atlas 14 for Arizona, Nevada, New Mexico, Utah and southeastern California. Visit the Precipitation Frequency Data Server for more information.

This web page provides access to high-resolution (15-sec) NOAA Atlas 2 precipitation frequency grids for 2-year and 100-year average recurrence intervals and for 6-hour and 24-hour durations for 7 states in the western U.S. (part of California, Colorado, Idaho, Montana, Oregon, Washington, Wyoming).

To view a scanned version of current NOAA Atlas 2 document for a specific state, please visit our PF Documents page.

To view a complete set of scanned maps from NOAA Atlas 2, visit the Western Regional Climate Center page.

- **PRECIPITATION FREQUENCY ESTIMATES AT A POINT**
  To obtain the precipitation frequency estimates at a given point, enter the latitude and longitude **(as a negative number)** in **decimal degrees**:

  Latitude: 46.6056 Longitude: -111.9636 Submit Reset

- **PRECIPITATION FREQUENCY GRIDS**
  These spatial data sets are provided in an ArcInfo ASCII grid format. Please read the **metadata** before making any use of the datasets.

  The files can either be downloaded via pull-down menu or anonymous ftp:

  1) Via pull-down menu:

  Western U.S. | 2-year, 6-hour | Download

At WRCC: www.wrcc.dri.edu/pcpnfreq.html

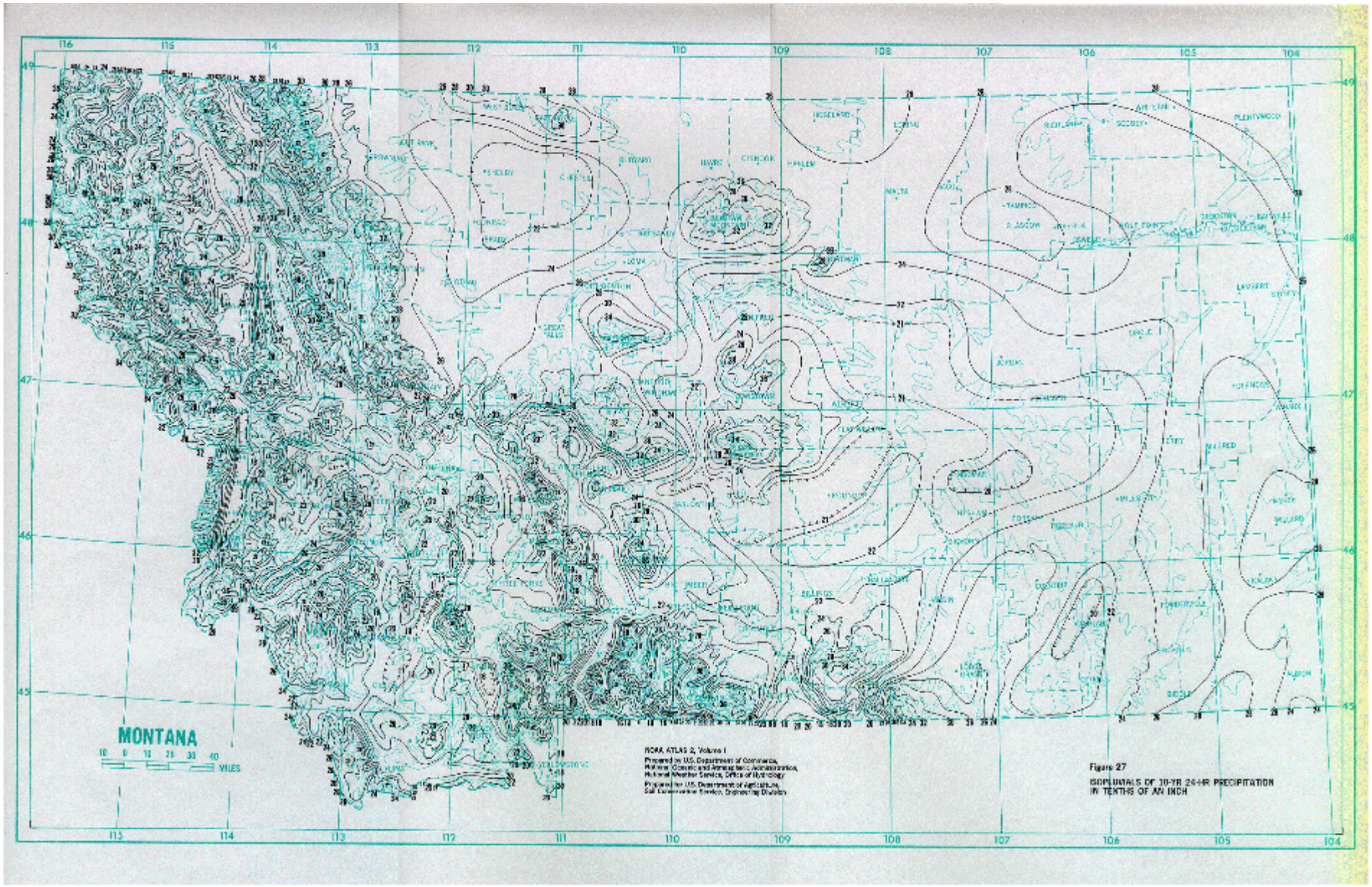
Western U.S. Precipitation Frequency Maps

Source: NOAA Atlas 2 published in 1973. (HDSC/NWS Office of Hydrology)
Note: To maintain image integrity and detail each image is almost 1 MB in size.
To obtain more information or the text material that accompanies these maps contact the Western Regional Climate Center at 775-674-7010
(wrcc@dri.edu)

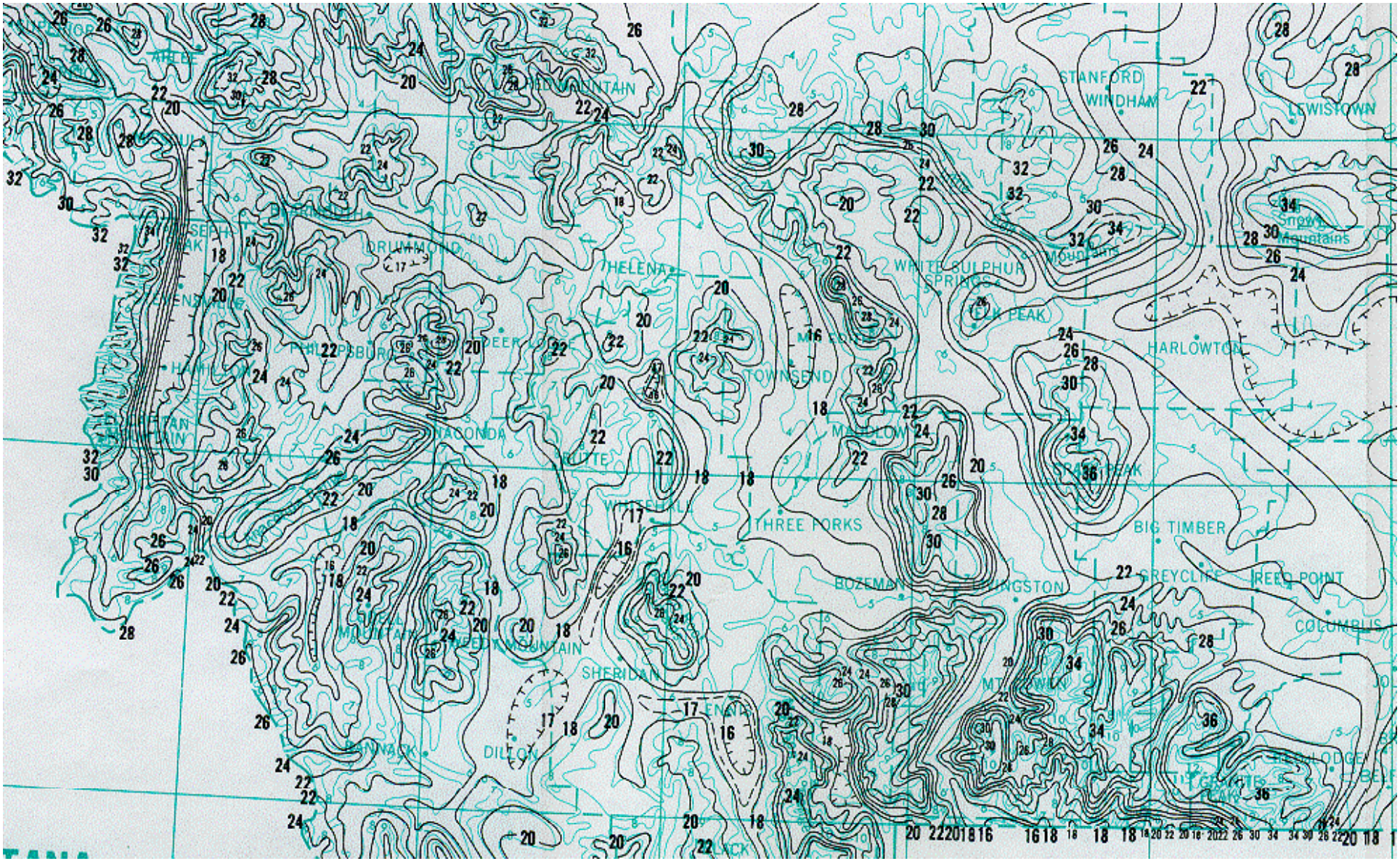
	2 Yr, 6 Hr	5 Yr, 6 Hr	10 Yr, 6 Hr	25 Yr, 6 Hr	50 Yr, 6 Hr	100 Yr, 6 Hr	2 Yr, 24 Hr	5 Yr, 24 Hr	10 Yr, 24 Hr	25 Yr, 24 Hr	50 Yr, 24 Hr	100 Yr, 24 Hr
Arizona	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Northern California	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Southern California	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Colorado	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Idaho	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Montana	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nevada	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
New Mexico	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Oregon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Utah	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Washington	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wyoming	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Western Regional Climate Center, wrcc@dri.edu

10-year 24-hour precipitation in tenths of inches



More detail … 10-year 24-hour precipitation in tenths of inches



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NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES

DATA DESCRIPTION

Data type: precipitation depth | Units: english | Time series type: annual maximum

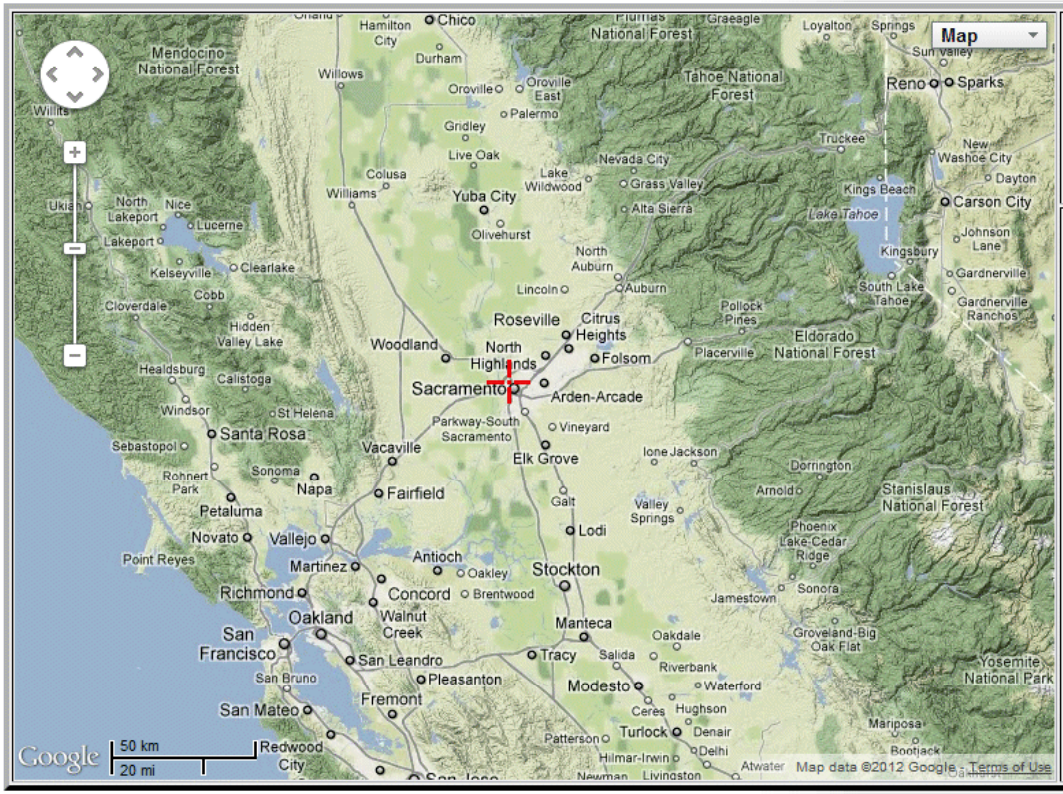
SELECT LOCATION

1. Manually:

a) Enter location (decimal degrees, use "-" for S and W): latitude: longitude: submit

b) Select station: select station

2. Use map:



a) Select location
(move crosshair or double click)

b) Click on station icon
(show stations on map)

LOCATION INFORMATION:
Name: Sacramento, California, US*
Latitude: 38.6071
Longitude: -121.5213
Elevation: 22 ft*

* source: Google Maps

POINT PRECIPITATION FREQUENCY (PF) ESTIMATES

WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION
NOAA Atlas 14, Volume 6, Version 2

AMS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
5-min	0.122 (0.111-0.136)	0.171 (0.154-0.191)	0.206 (0.184-0.233)	0.256 (0.217-0.305)	0.299 (0.245-0.367)	0.346 (0.274-0.441)	0.398 (0.302-0.528)	0.476 (0.341-0.671)	0.543 (0.371-0.804)
10-min	0.175 (0.159-0.195)	0.245 (0.221-0.273)	0.295 (0.263-0.333)	0.367 (0.311-0.437)	0.428 (0.352-0.526)	0.495 (0.392-0.631)	0.570 (0.433-0.757)	0.682 (0.489-0.961)	0.779 (0.531-1.15)
15-min	0.212 (0.192-0.236)	0.296 (0.267-0.331)	0.356 (0.318-0.403)	0.444 (0.376-0.529)	0.518 (0.425-0.636)	0.599 (0.474-0.764)	0.689 (0.524-0.915)	0.825 (0.591-1.16)	0.942 (0.643-1.39)
30-min	0.295 (0.268-0.329)	0.412 (0.372-0.460)	0.497 (0.443-0.562)	0.618 (0.524-0.737)	0.721 (0.592-0.886)	0.834 (0.661-1.06)	0.960 (0.730-1.27)	1.15 (0.823-1.62)	1.31 (0.895-1.94)
60-min	0.409 (0.371-0.456)	0.570 (0.515-0.638)	0.688 (0.614-0.778)	0.856 (0.726-1.02)	0.998 (0.820-1.23)	1.16 (0.915-1.47)	1.33 (1.01-1.77)	1.59 (1.14-2.24)	1.82 (1.24-2.69)
2-hr	0.594 (0.538-0.661)	0.809 (0.731-0.904)	0.960 (0.857-1.09)	1.17 (0.993-1.40)	1.34 (1.10-1.65)	1.53 (1.21-1.95)	1.73 (1.32-2.30)	2.03 (1.46-2.86)	2.28 (1.55-3.37)
3-hr	0.741 (0.672-0.825)	1.00 (0.908-1.12)	1.19 (1.06-1.34)	1.44 (1.22-1.71)	1.64 (1.35-2.02)	1.86 (1.47-2.37)	2.09 (1.59-2.78)	2.43 (1.74-3.42)	2.71 (1.85-4.00)
6-hr	1.04 (0.942-1.16)	1.42 (1.28-1.58)	1.67 (1.49-1.89)	2.01 (1.71-2.40)	2.28 (1.87-2.81)	2.56 (2.03-3.27)	2.86 (2.18-3.80)	3.28 (2.35-4.62)	3.62 (2.47-5.36)
12-hr	1.39 (1.26-1.55)	1.99 (1.80-2.22)	2.38 (2.13-2.69)	2.90 (2.46-3.45)	3.30 (2.71-4.05)	3.71 (2.94-4.73)	4.14 (3.15-5.49)	4.73 (3.39-6.66)	5.19 (3.54-7.69)
24-hr	1.87 (1.72-2.08)	2.79 (2.55-3.11)	3.38 (3.07-3.79)	4.15 (3.65-4.81)	4.74 (4.09-5.59)	5.33 (4.50-6.45)	5.95 (4.89-7.38)	6.79 (5.37-8.74)	7.44 (5.71-9.90)
2-day	2.43 (2.22-2.70)	3.55 (3.25-3.96)	4.27 (3.88-4.79)	5.18 (4.57-6.01)	5.88 (5.08-6.94)	6.57 (5.55-7.94)	7.27 (5.98-9.02)	8.21 (6.50-10.6)	8.94 (6.86-11.9)
3-day	2.81 (2.58-3.13)	4.06 (3.72-4.53)	4.85 (4.41-5.45)	5.86 (5.16-6.79)	6.61 (5.71-7.81)	7.36 (6.22-8.90)	8.12 (6.68-10.1)	9.12 (7.22-11.8)	9.89 (7.59-13.2)
4-day	3.11 (2.85-3.46)	4.48 (4.10-5.00)	5.34 (4.85-6.00)	6.42 (5.65-7.44)	7.22 (6.24-8.54)	8.02 (6.77-9.70)	8.82 (7.26-10.9)	9.88 (7.82-12.7)	10.7 (8.19-14.2)
7-day	3.82 (3.50-4.25)	5.50 (5.04-6.14)	6.54 (5.94-7.34)	7.82 (6.88-9.06)	8.75 (7.56-10.3)	9.66 (8.16-11.7)	10.6 (8.69-13.1)	11.7 (9.29-15.1)	12.6 (9.66-16.8)
10-day	4.29 (3.93-4.77)	6.20 (5.67-6.92)	7.36 (6.68-8.26)	8.77 (7.72-10.2)	9.79 (8.45-11.6)	10.8 (9.10-13.0)	11.7 (9.66-14.6)	13.0 (10.3-16.7)	13.9 (10.7-18.5)
20-day	5.55 (5.09-6.17)	8.02 (7.34-8.94)	9.48 (8.62-10.7)	11.3 (9.91-13.0)	12.5 (10.8-14.8)	13.7 (11.6-16.6)	14.9 (12.3-18.5)	16.4 (13.0-21.1)	17.5 (13.4-23.2)
30-day	6.68 (6.13-7.44)	9.61 (8.79-10.7)	11.3 (10.3-12.7)	13.4 (11.8-15.6)	14.9 (12.9-17.6)	16.3 (13.8-19.7)	17.7 (14.5-21.9)	19.4 (15.4-25.0)	20.6 (15.8-27.5)
45-day	8.14 (7.47-9.06)	11.6 (10.6-12.9)	13.6 (12.4-15.3)	16.0 (14.1-18.6)	17.8 (15.3-21.0)	19.4 (16.4-23.5)	21.0 (17.3-26.0)	23.0 (18.2-29.6)	24.4 (18.7-32.5)
60-day	9.70 (8.89-10.8)	13.6 (12.5-15.2)	15.9 (14.5-17.9)	18.7 (16.5-21.7)	20.7 (17.9-24.4)	22.6 (19.0-27.3)	24.4 (20.1-30.2)	26.7 (21.1-34.3)	28.3 (21.7-37.7)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of annual maxima series (AMS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and annual exceedance probability) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

HDSC

Sacra-mento

DDF

Table with c.i.

NOAA Atlas 14

AMS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

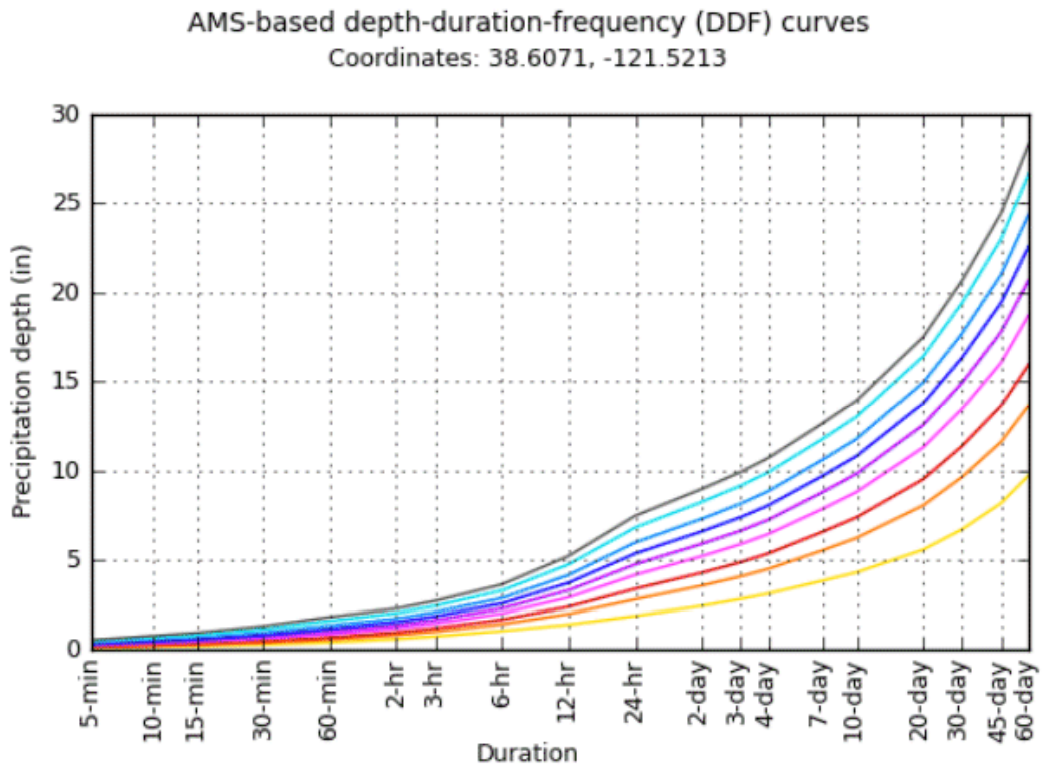
Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
5-min	1.46 (1.33-1.63)	2.05 (1.85-2.29)	2.47 (2.21-2.80)	3.07 (2.60-3.66)	3.59 (2.94-4.40)	4.15 (3.29-5.29)	4.78 (3.62-6.34)	5.71 (4.09-8.05)	6.52 (4.45-9.65)
10-min	1.05 (0.954-1.17)	1.47 (1.33-1.64)	1.77 (1.58-2.00)	2.20 (1.87-2.62)	2.57 (2.11-3.16)	2.97 (2.35-3.79)	3.42 (2.60-4.54)	4.09 (2.93-5.77)	4.67 (3.19-6.91)
15-min	0.848 (0.768-0.944)	1.18 (1.07-1.32)	1.42 (1.27-1.61)	1.78 (1.50-2.12)	2.07 (1.70-2.54)	2.40 (1.90-3.06)	2.76 (2.10-3.66)	3.30 (2.36-4.65)	3.77 (2.57-5.57)
30-min	0.590 (0.536-0.658)	0.824 (0.744-0.920)	0.994 (0.886-1.12)	1.24 (1.05-1.47)	1.44 (1.18-1.77)	1.67 (1.32-2.13)	1.92 (1.46-2.55)	2.30 (1.65-3.24)	2.62 (1.79-3.88)
60-min	0.409 (0.371-0.456)	0.570 (0.515-0.638)	0.688 (0.614-0.778)	0.856 (0.726-1.02)	0.998 (0.820-1.23)	1.16 (0.915-1.47)	1.33 (1.01-1.77)	1.59 (1.14-2.24)	1.82 (1.24-2.69)
2-hr	0.297 (0.269-0.330)	0.404 (0.366-0.452)	0.480 (0.428-0.543)	0.586 (0.496-0.698)	0.672 (0.552-0.826)	0.766 (0.606-0.976)	0.867 (0.660-1.15)	1.01 (0.728-1.43)	1.14 (0.778-1.69)
3-hr	0.247 (0.224-0.275)	0.335 (0.302-0.374)	0.396 (0.353-0.447)	0.479 (0.406-0.571)	0.547 (0.449-0.672)	0.619 (0.490-0.789)	0.696 (0.529-0.925)	0.808 (0.579-1.14)	0.901 (0.615-1.33)
6-hr	0.173 (0.157-0.193)	0.236 (0.214-0.265)	0.279 (0.249-0.316)	0.336 (0.285-0.400)	0.381 (0.313-0.468)	0.428 (0.339-0.546)	0.478 (0.363-0.634)	0.548 (0.392-0.772)	0.604 (0.412-0.894)
12-hr	0.116 (0.105-0.129)	0.165 (0.149-0.185)	0.198 (0.176-0.224)	0.240 (0.204-0.286)	0.274 (0.225-0.336)	0.308 (0.244-0.393)	0.343 (0.261-0.456)	0.392 (0.281-0.553)	0.431 (0.294-0.638)
24-hr	0.078 (0.072-0.087)	0.116 (0.106-0.130)	0.141 (0.128-0.158)	0.173 (0.152-0.200)	0.197 (0.170-0.233)	0.222 (0.188-0.269)	0.248 (0.204-0.307)	0.283 (0.224-0.364)	0.310 (0.238-0.412)
2-day	0.051 (0.046-0.056)	0.074 (0.068-0.083)	0.089 (0.081-0.100)	0.108 (0.095-0.125)	0.122 (0.106-0.145)	0.137 (0.116-0.165)	0.151 (0.125-0.188)	0.171 (0.135-0.220)	0.186 (0.143-0.248)
3-day	0.039 (0.036-0.043)	0.056 (0.052-0.063)	0.067 (0.061-0.076)	0.081 (0.072-0.094)	0.092 (0.079-0.108)	0.102 (0.086-0.124)	0.113 (0.093-0.140)	0.127 (0.100-0.163)	0.137 (0.105-0.183)
4-day	0.032 (0.030-0.036)	0.047 (0.043-0.052)	0.056 (0.051-0.062)	0.067 (0.059-0.078)	0.075 (0.065-0.089)	0.084 (0.071-0.101)	0.092 (0.076-0.114)	0.103 (0.081-0.133)	0.111 (0.085-0.148)
7-day	0.023 (0.021-0.025)	0.033 (0.030-0.037)	0.039 (0.035-0.044)	0.047 (0.041-0.054)	0.052 (0.045-0.062)	0.058 (0.049-0.070)	0.063 (0.052-0.078)	0.070 (0.055-0.090)	0.075 (0.058-0.100)
10-day	0.018 (0.016-0.020)	0.026 (0.024-0.029)	0.031 (0.028-0.034)	0.037 (0.032-0.042)	0.041 (0.035-0.048)	0.045 (0.038-0.054)	0.049 (0.040-0.061)	0.054 (0.043-0.070)	0.058 (0.044-0.077)
20-day	0.012 (0.011-0.013)	0.017 (0.015-0.019)	0.020 (0.018-0.022)	0.023 (0.021-0.027)	0.026 (0.023-0.031)	0.029 (0.024-0.035)	0.031 (0.026-0.038)	0.034 (0.027-0.044)	0.036 (0.028-0.048)
30-day	0.009 (0.009-0.010)	0.013 (0.012-0.015)	0.016 (0.014-0.018)	0.019 (0.016-0.022)	0.021 (0.018-0.024)	0.023 (0.019-0.027)	0.025 (0.020-0.030)	0.027 (0.021-0.035)	0.029 (0.022-0.038)
45-day	0.008 (0.007-0.008)	0.011 (0.010-0.012)	0.013 (0.011-0.014)	0.015 (0.013-0.017)	0.016 (0.014-0.019)	0.018 (0.015-0.022)	0.019 (0.016-0.024)	0.021 (0.017-0.027)	0.023 (0.017-0.030)
60-day	0.007 (0.006-0.007)	0.009 (0.009-0.011)	0.011 (0.010-0.012)	0.013 (0.011-0.015)	0.014 (0.012-0.017)	0.016 (0.013-0.019)	0.017 (0.014-0.021)	0.019 (0.015-0.024)	0.020 (0.015-0.026)

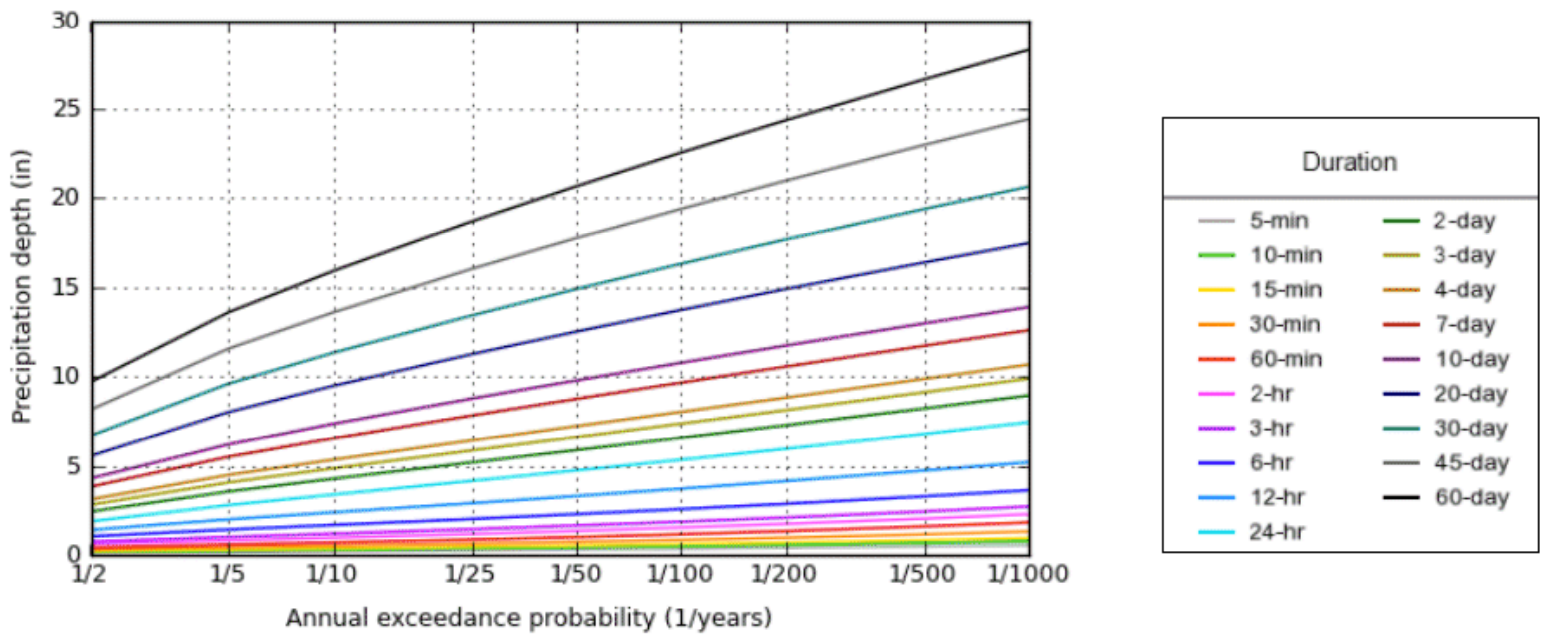
[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of annual maxima series (AMS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and annual exceedance probability) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

HDSC Sacra-mento IDF Table with c.i. NOAA Atlas 14





HDSC

Sacramento

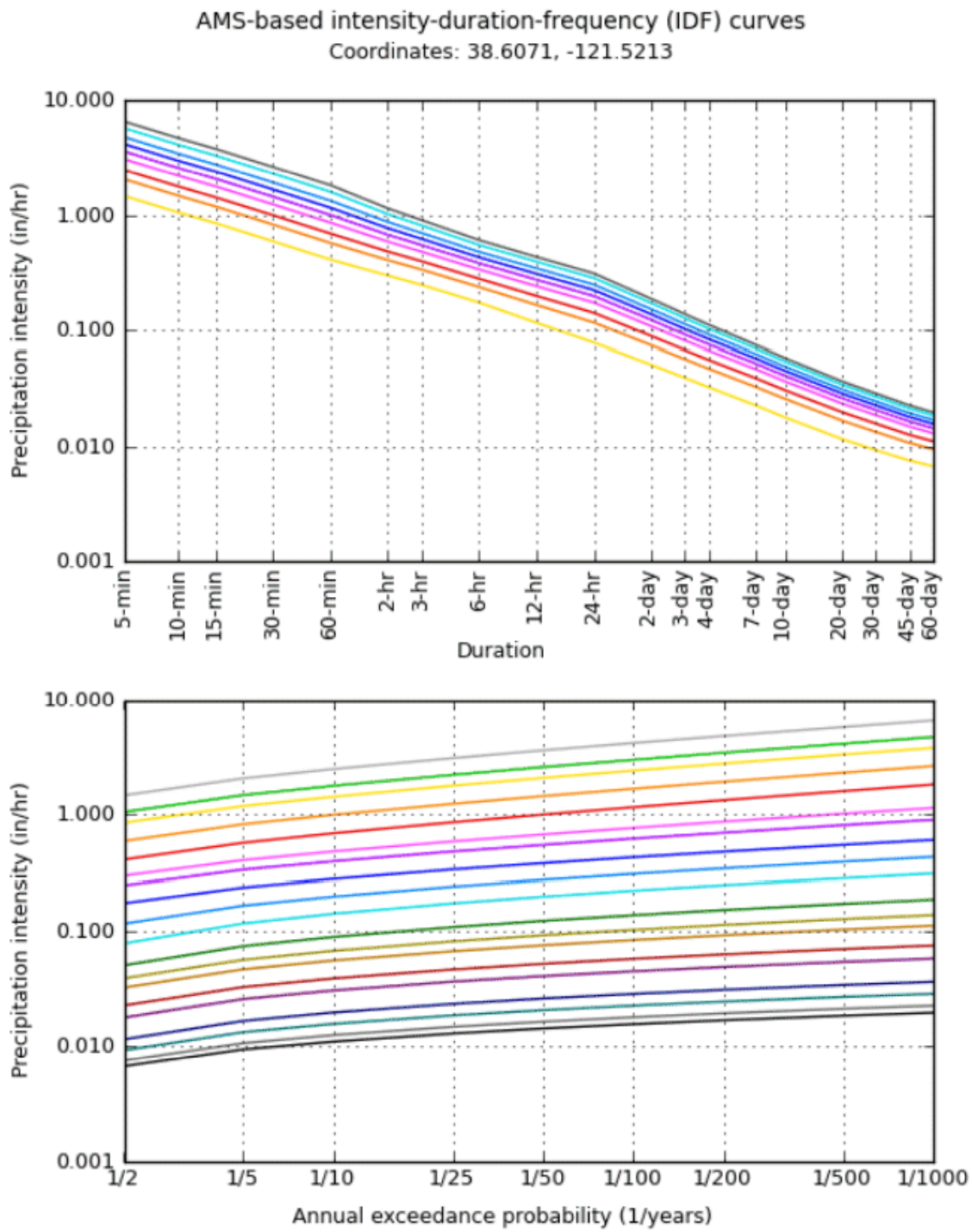
DDF

Depth-Duration-Frequency

Precip Total

NOAA Atlas 14

Based on Annual Maximum Series (Max each yr)



HDSC

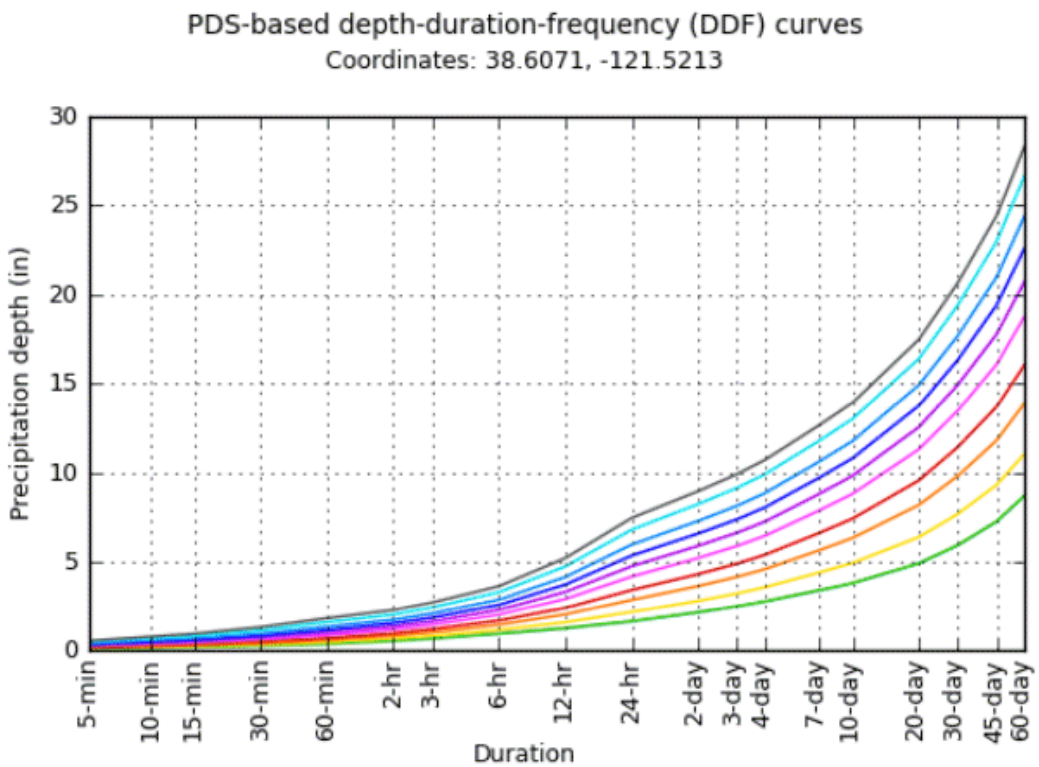
Sacramento

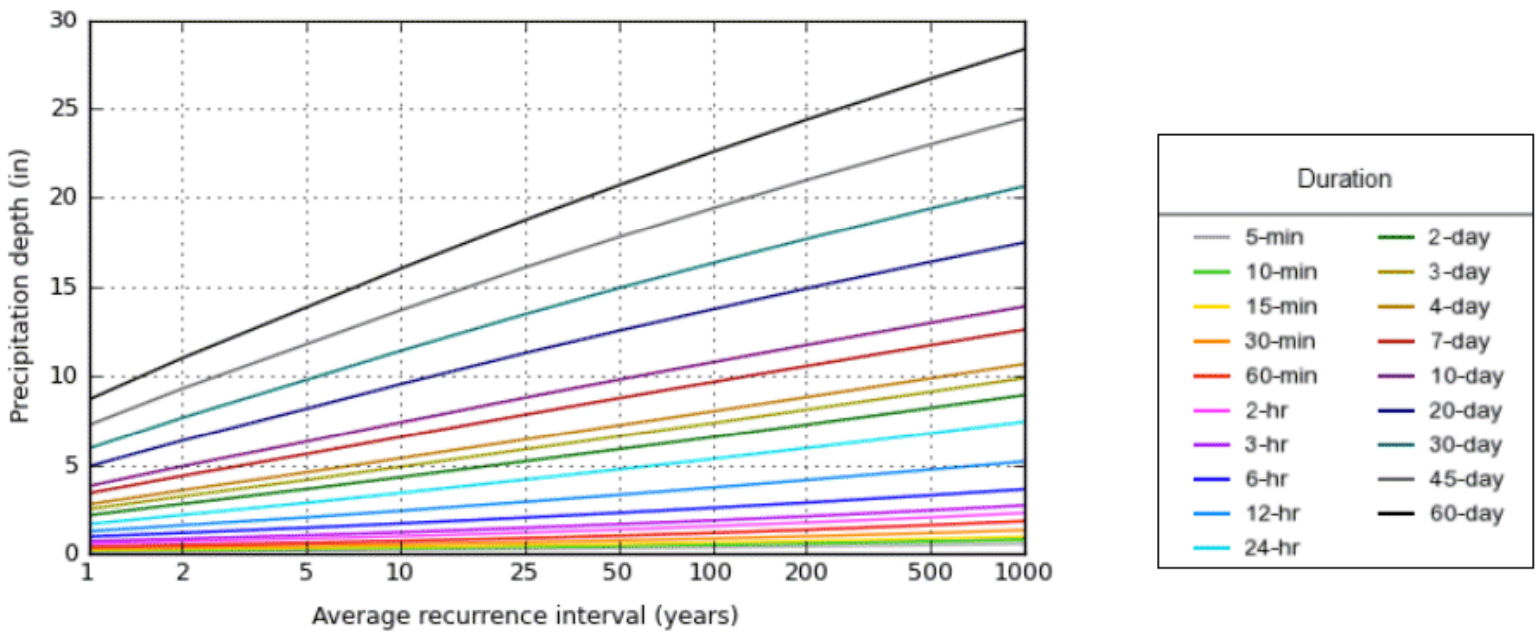
IDF

Intensity-Duration-Frequency

Precip Rate

NOAA Atlas 14





HDSC

Sacramento

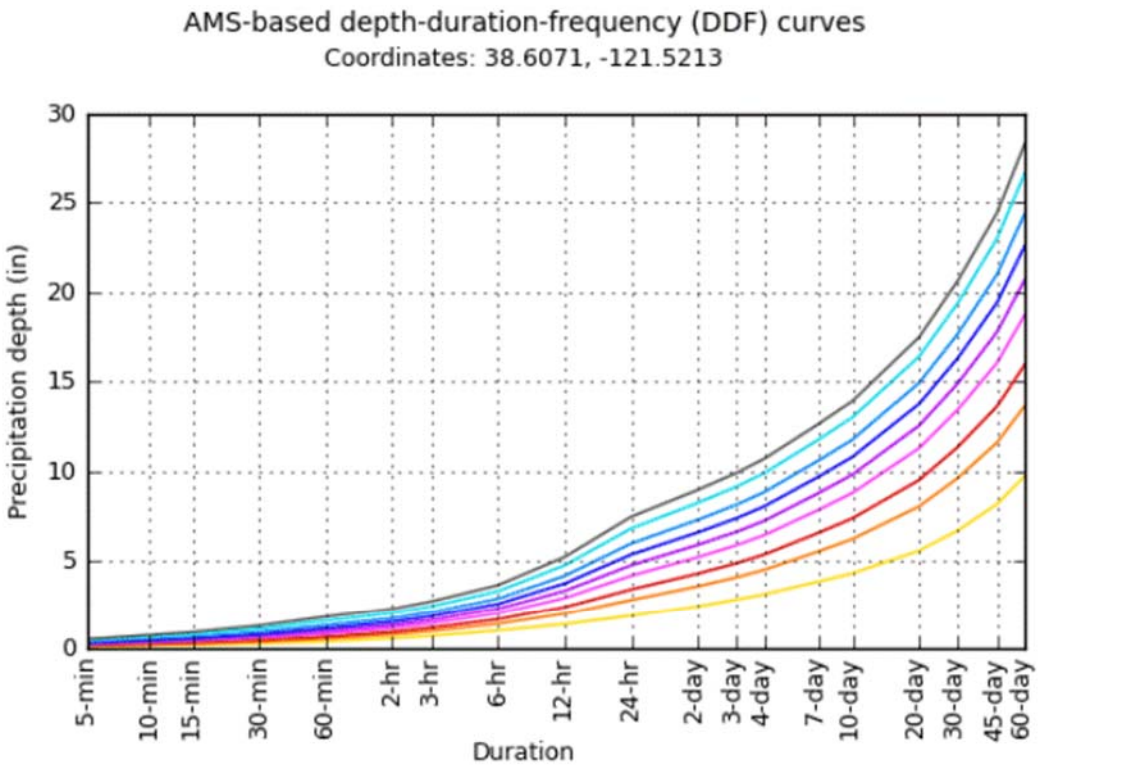
DDF

Depth-Duration-Frequency

Precip Total

NOAA Atlas 14

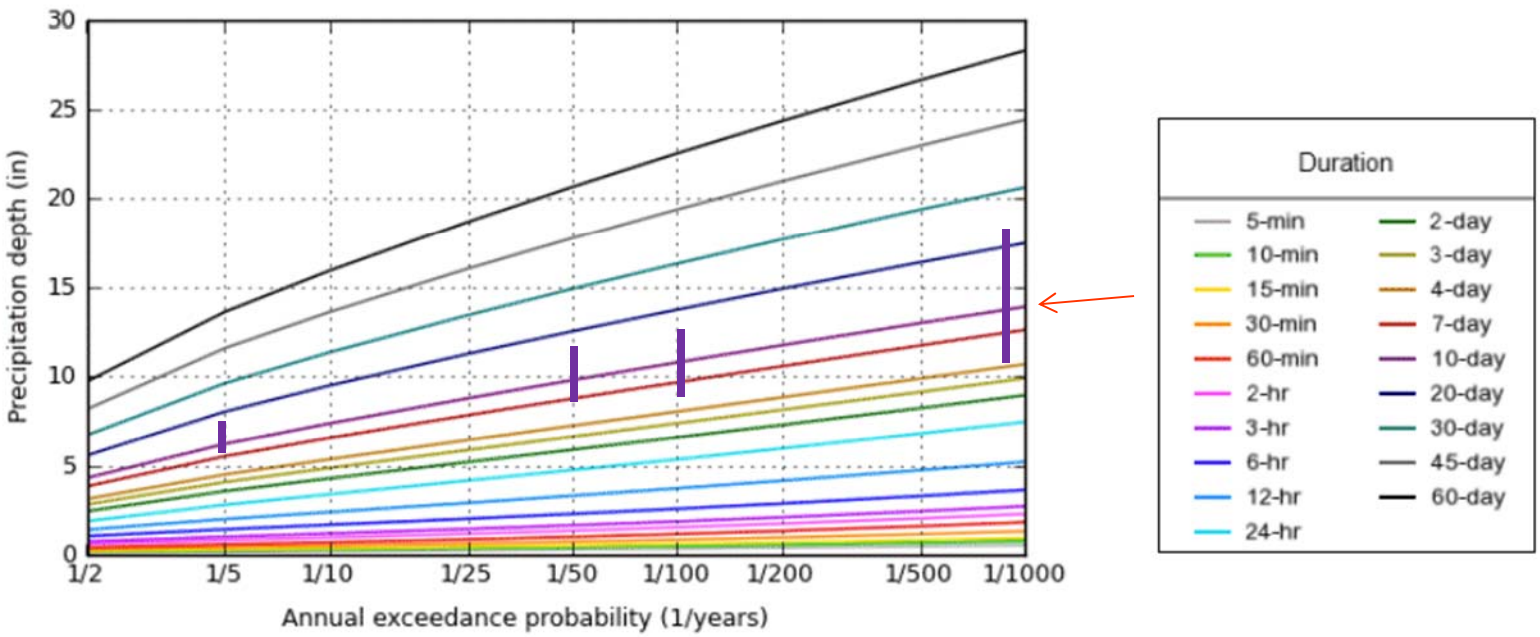
Based on Partial Duration Series (N-Highest Max values)



HDSC

Sacramento

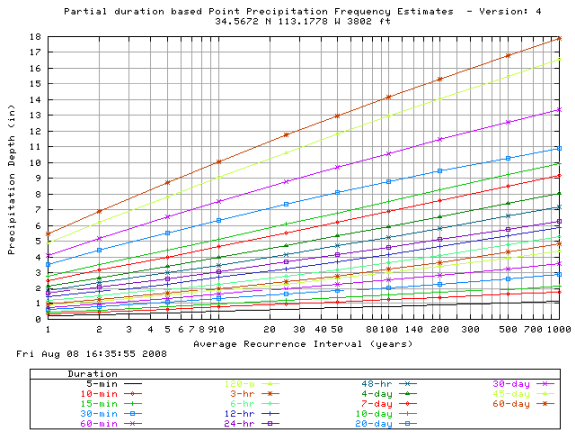
DDF



90 % confidence interval (5-95 %) for 10-day duration

The Central Question of Precipitation Non-Stationarity:

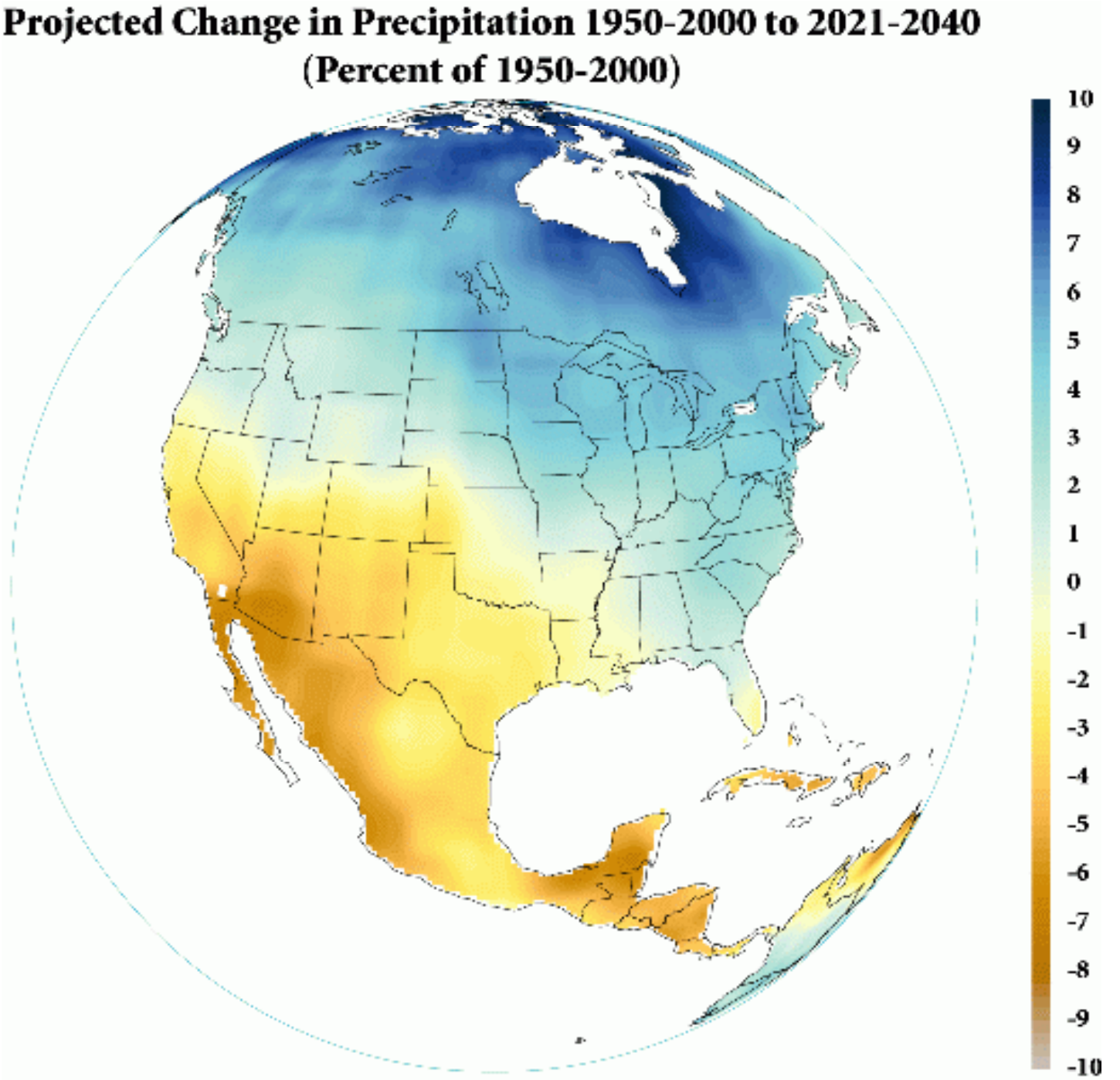
What is

d 

/ dt

???

How do the lines on this diagram move around with time?
Slope? Position? Spacing? At what rate?



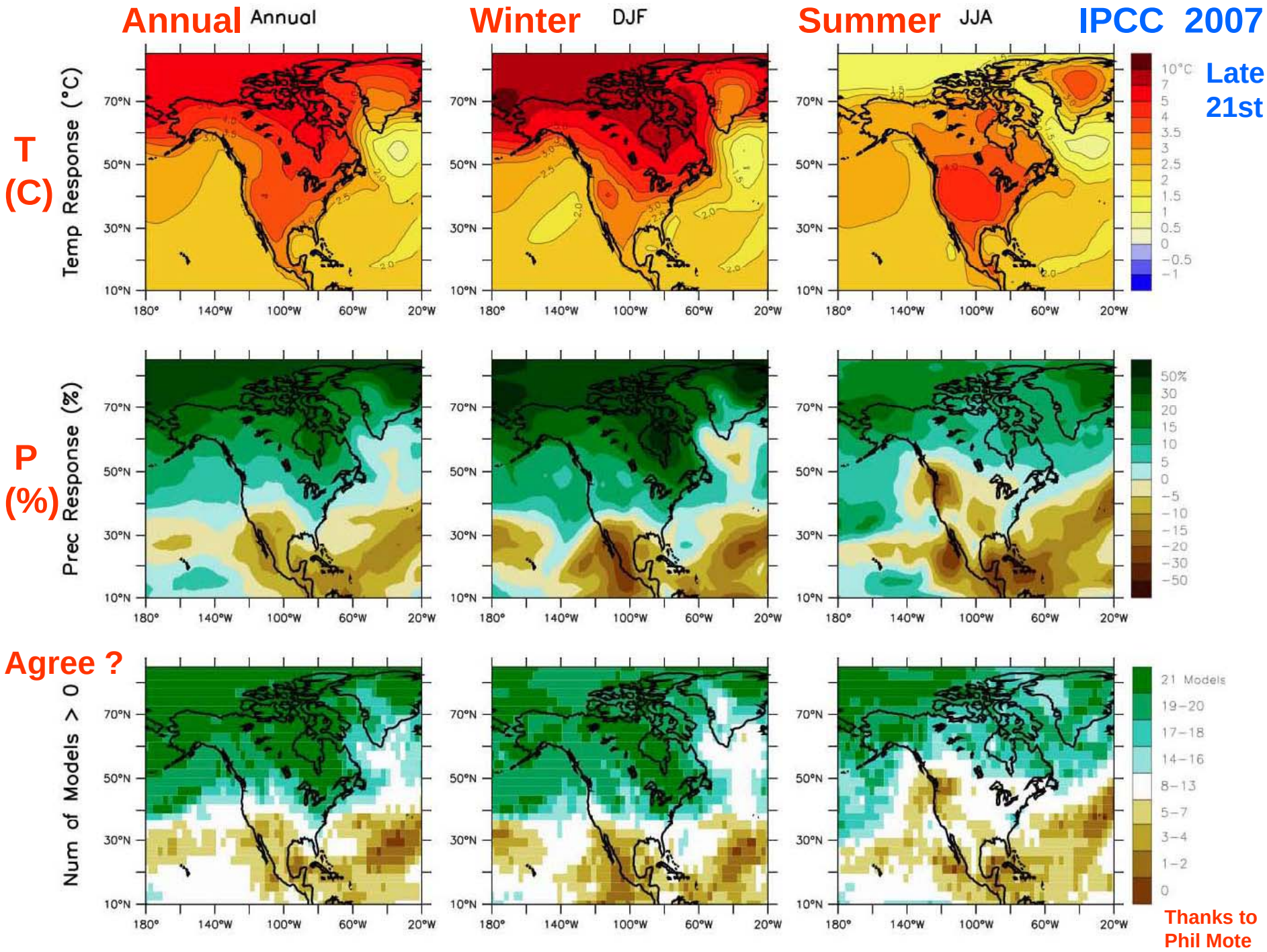
Average of 19 climate models. 2007.

20 years from 2010.

Figure by Gabriel Vecchi.

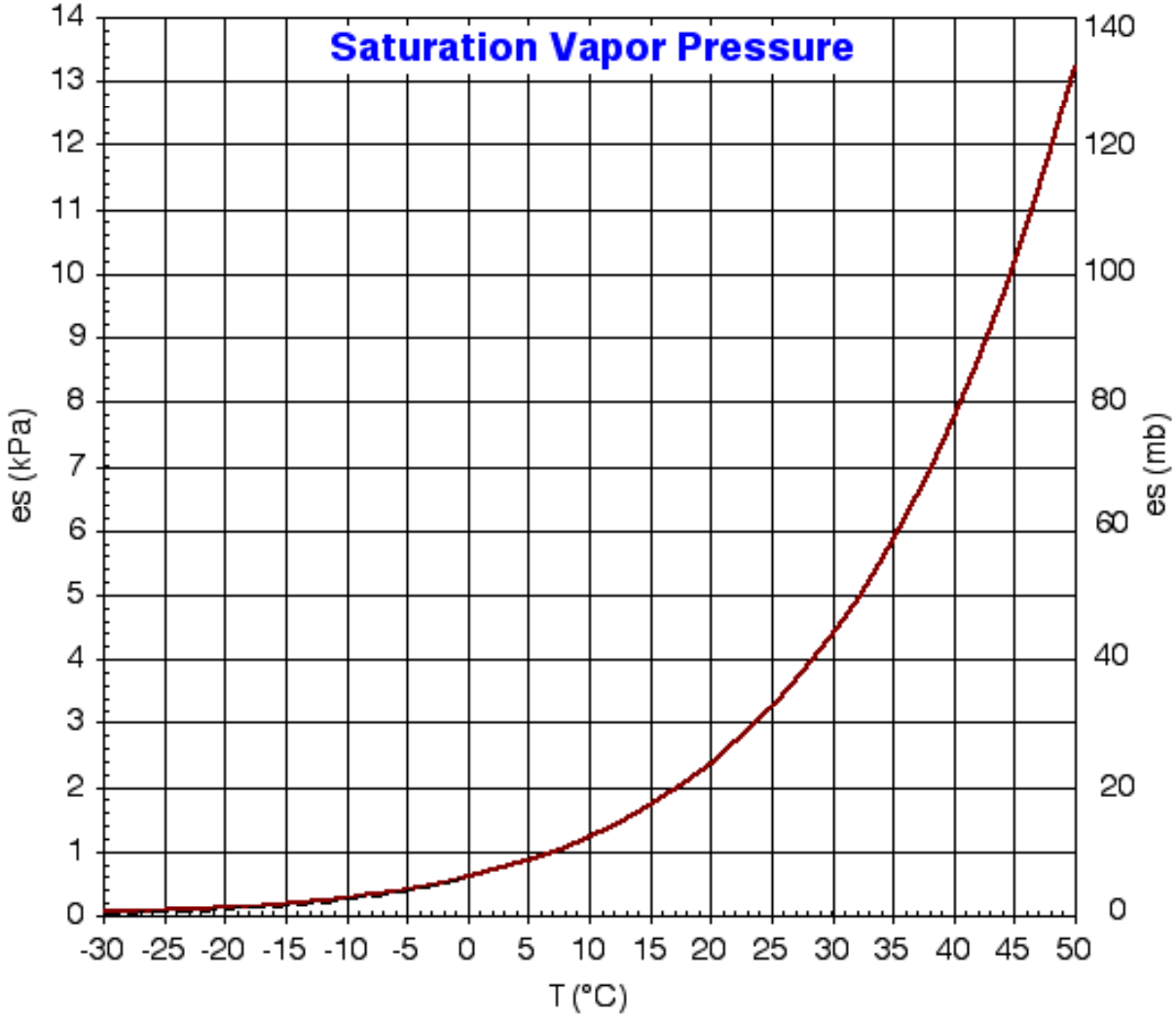
www.ldeo.columbia.edu/res/div/ocp/drought/science.shtml

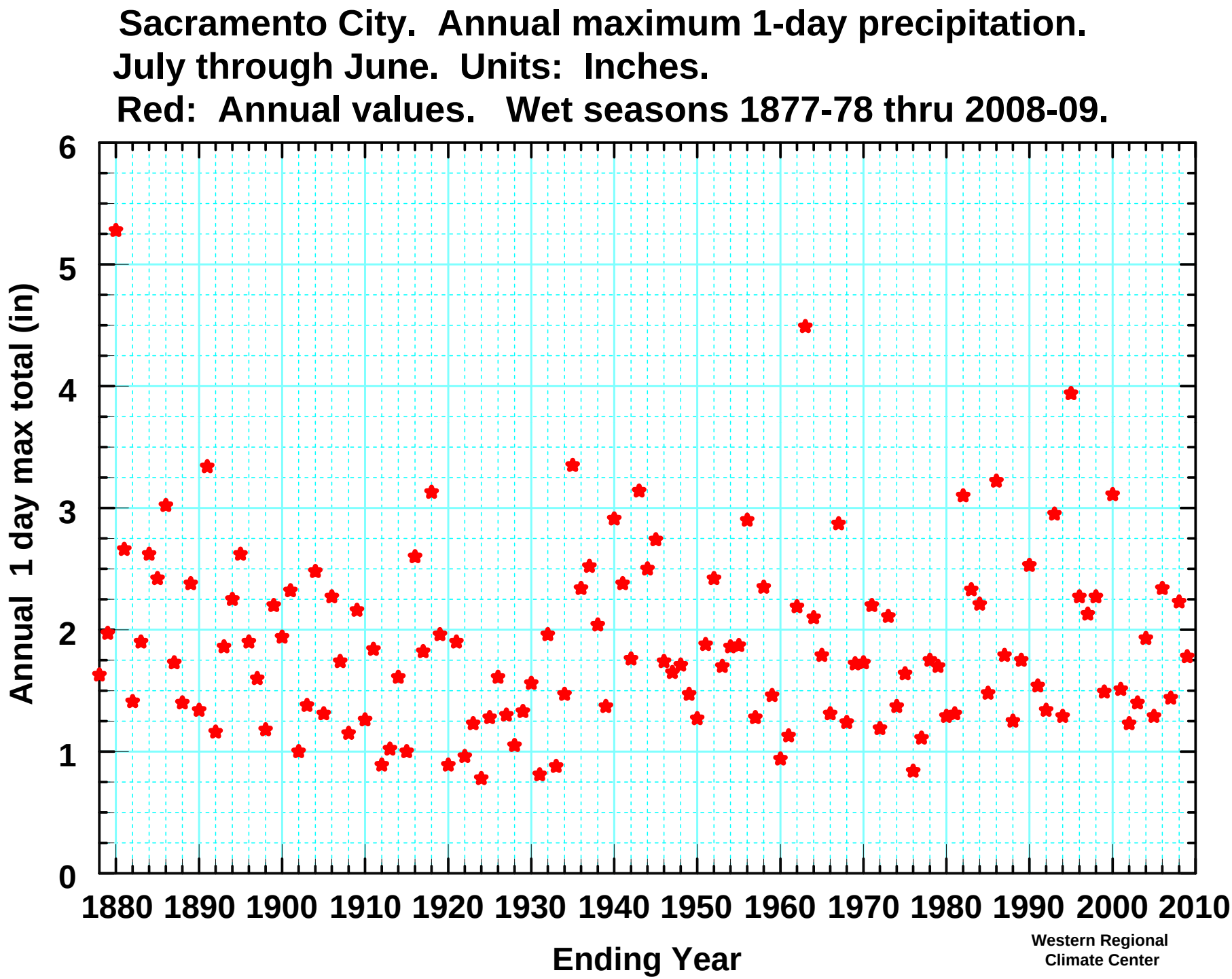
R. Seager, M.F. Ting, I.M. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, N. Naik, 2007. Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America. *Science*, DOI: 10.1126/science.1139601

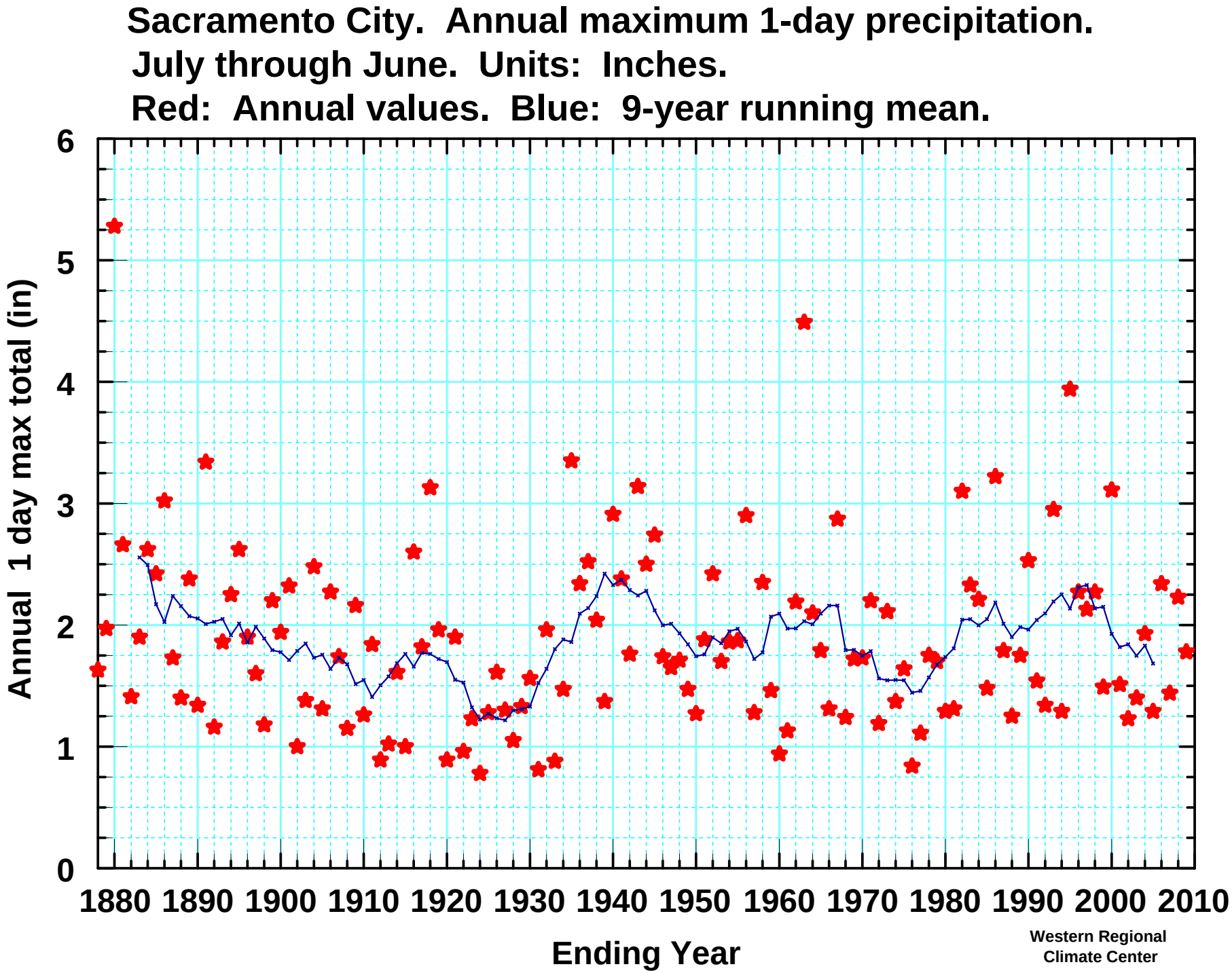

Annual Annual
Winter DJF
Summer JJA
IPCC 2007
Late 21st
T (C)
Temp Response (°C)
P (%)
Prec Response (%)
Agree ?
Num of Models > 0
70°N
50°N
30°N
10°N
180°
140°W
100°W
60°W
20°W
10°C
7
5
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
50%
30
20
15
10
5
0
−5
−10
−15
−20
−30
−50
21 Models
19−20
17−18
14−16
8−13
5−7
3−4
1−2
0
Thanks to Phil Mote

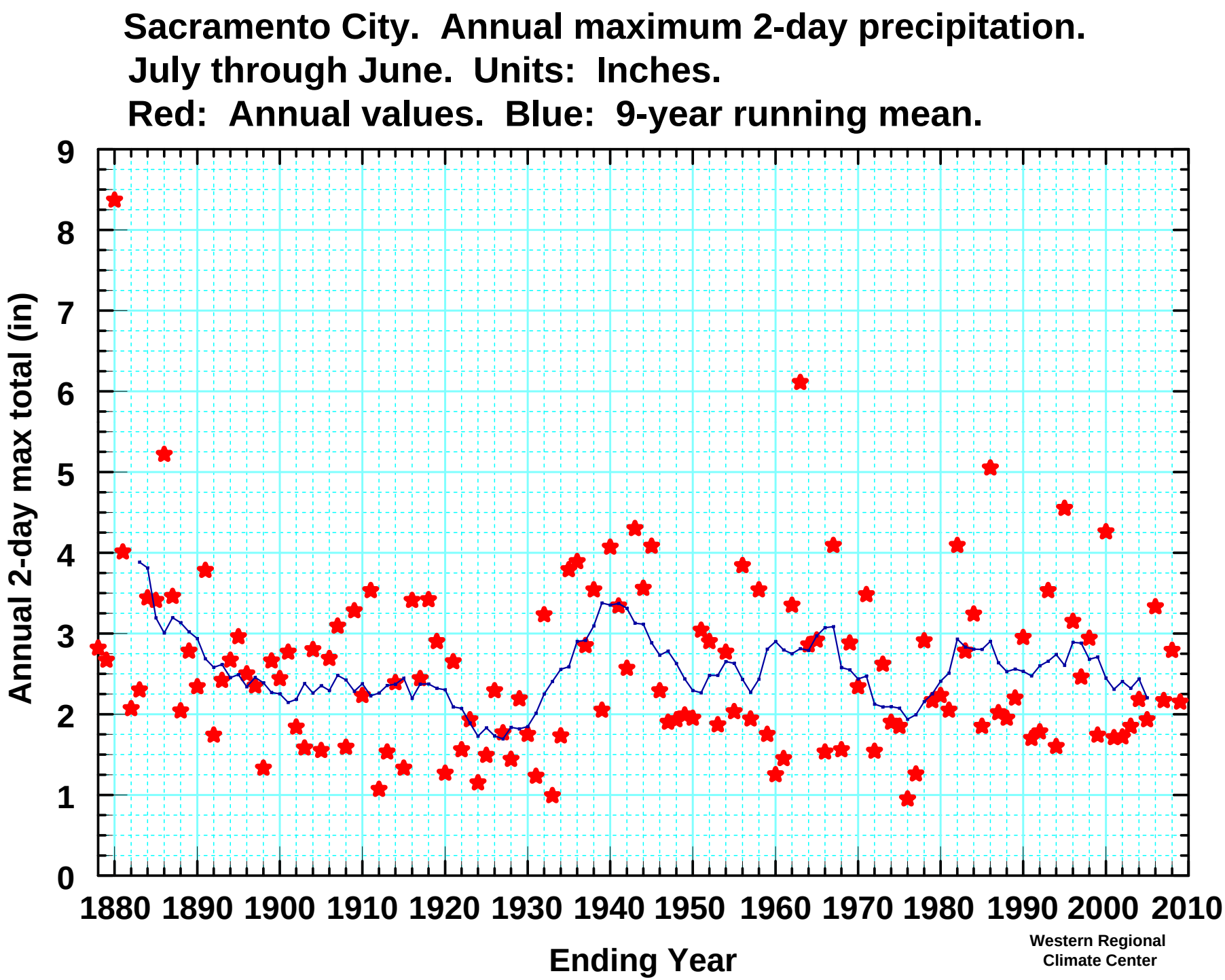
Clausius-Clapeyron relation for plane (flat) water surface

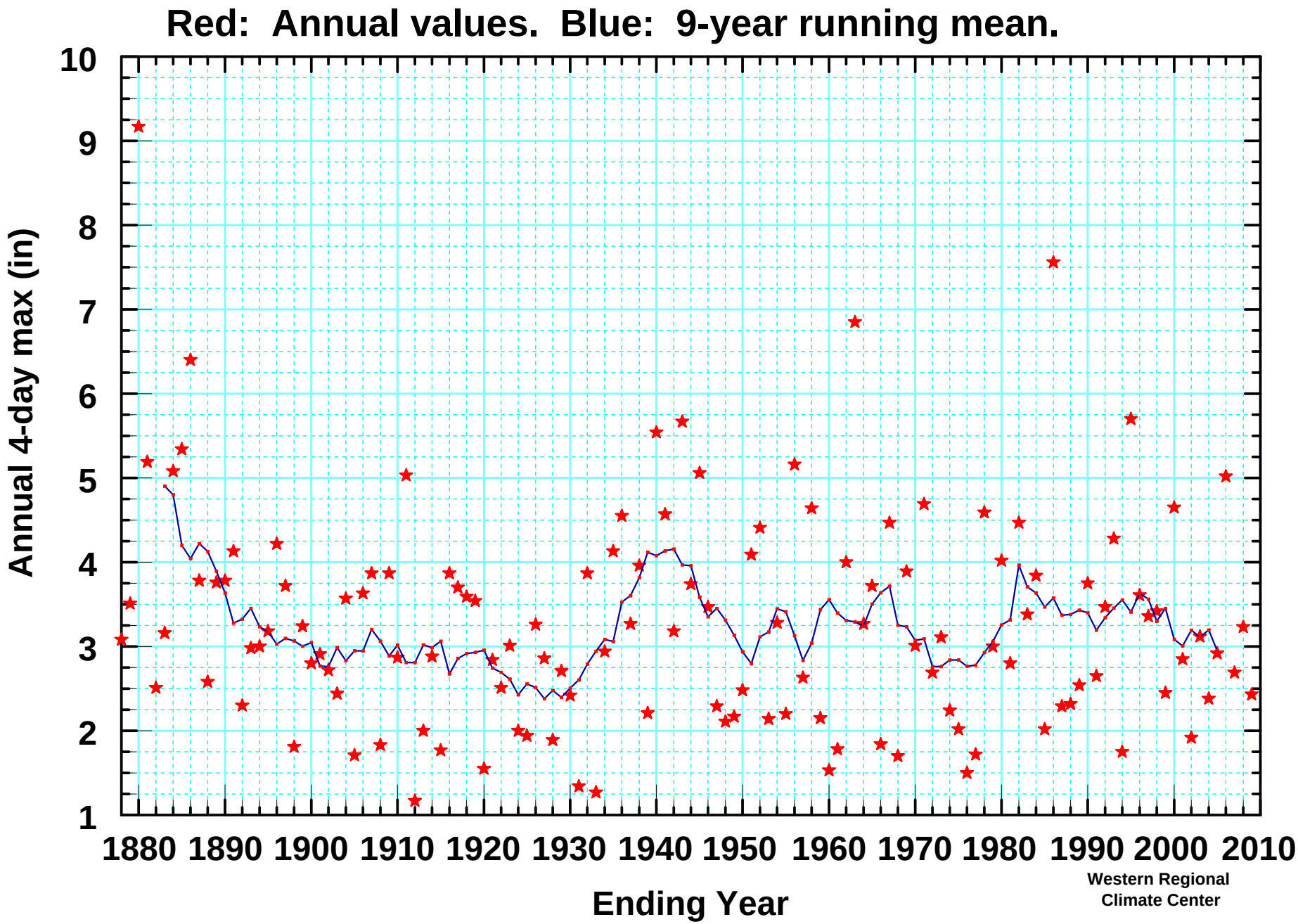
Saturation vapor pressure increases about 1/3 per 5 C increase

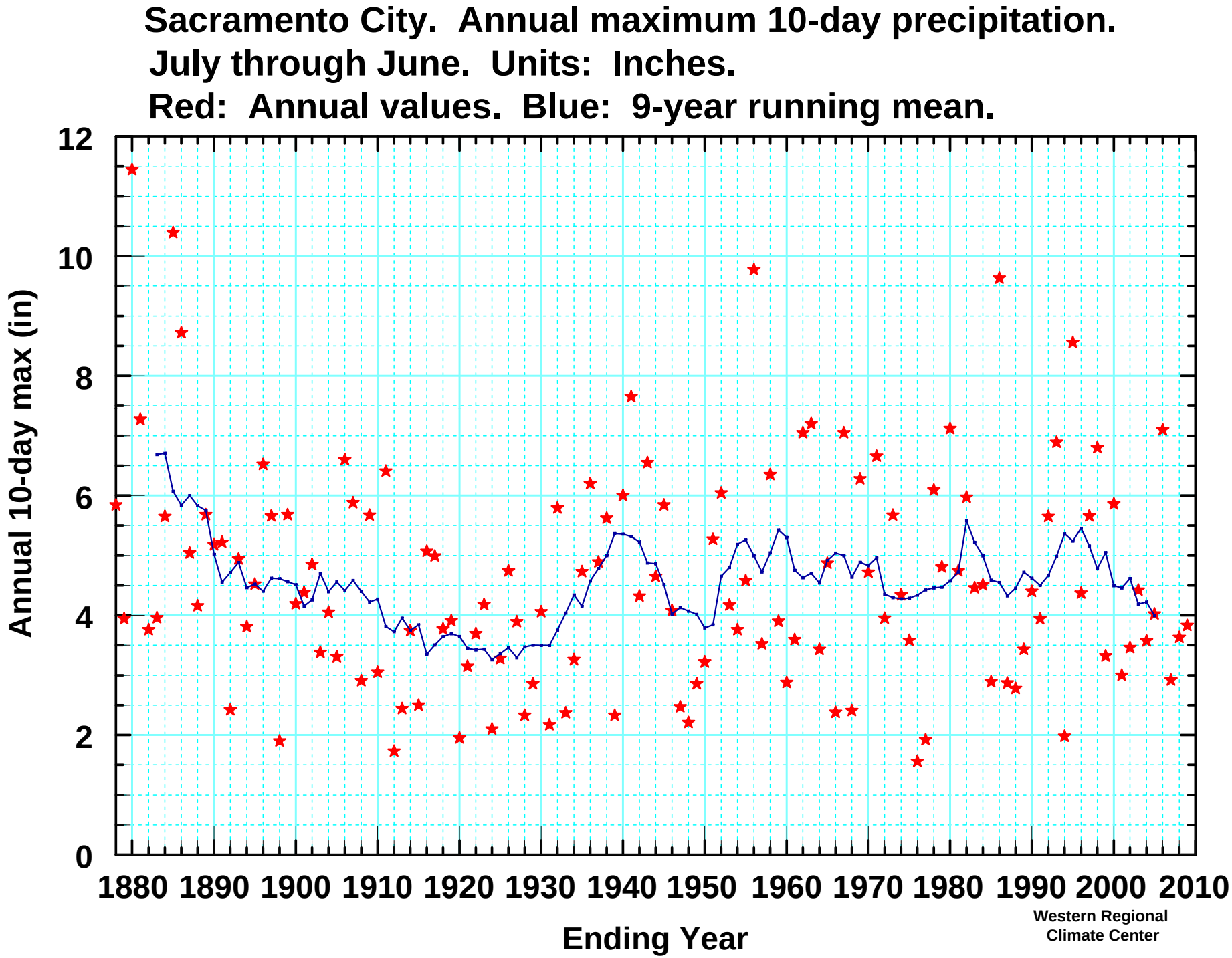


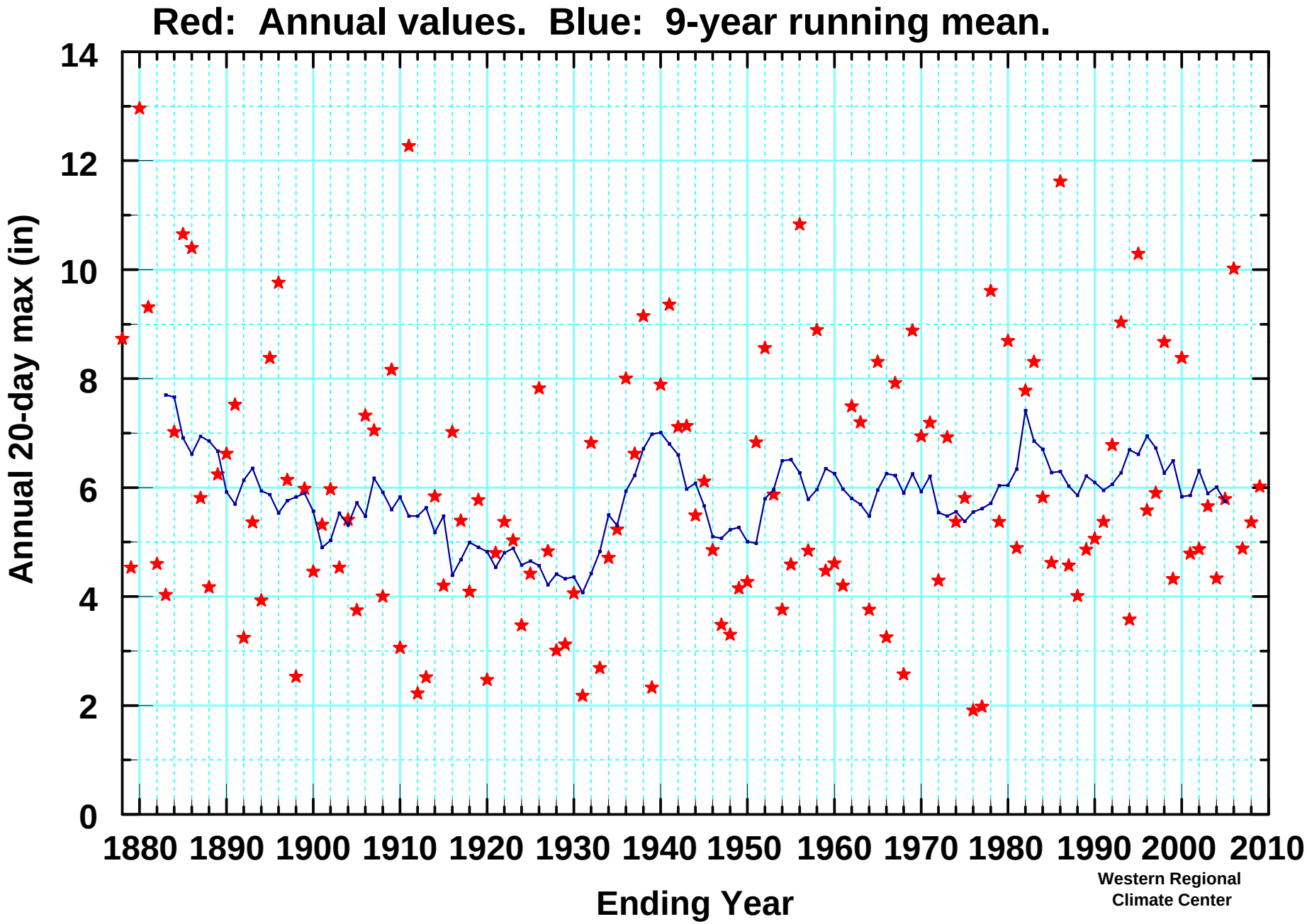

Sacramento City. Annual maximum 1-day precipitation.
July through June. Units: Inches.
Red: Annual values. Wet seasons 1877-78 thru 2008-09.
Annual 1 day max total (in)
0
1
2
3
4
5
6
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Ending Year
Western Regional
Climate Center

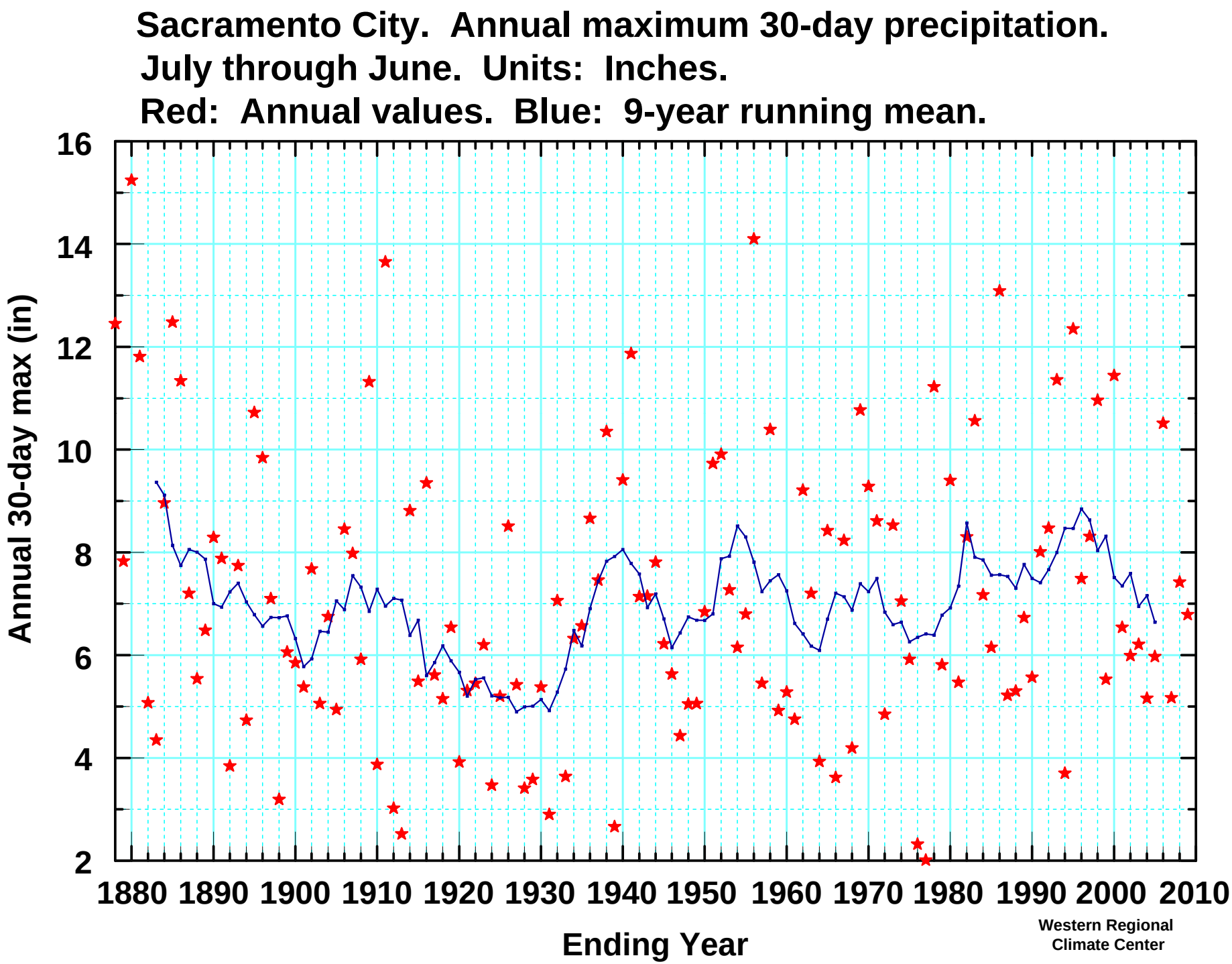

Sacramento City. Annual maximum 1-day precipitation.
July through June. Units: Inches.
Red: Annual values. Blue: 9-year running mean.
Annual 1 day max total (in)
0
1
2
3
4
5
6
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Ending Year
Western Regional
Climate Center

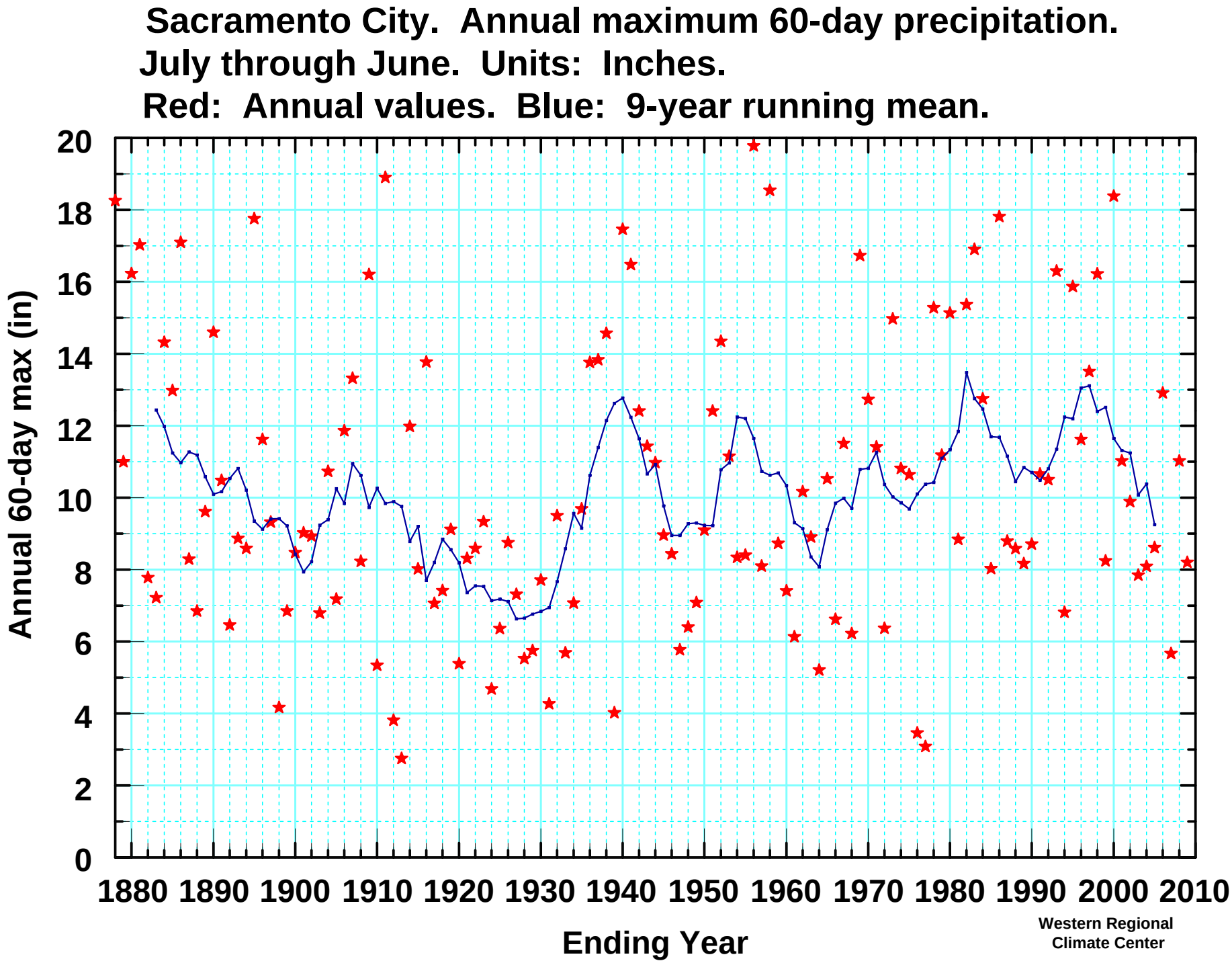

Sacramento City. Annual maximum 2-day precipitation.
July through June. Units: Inches.
Red: Annual values. Blue: 9-year running mean.
Annual 2-day max total (in)
0
1
2
3
4
5
6
7
8
9
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Ending Year
Western Regional
Climate Center

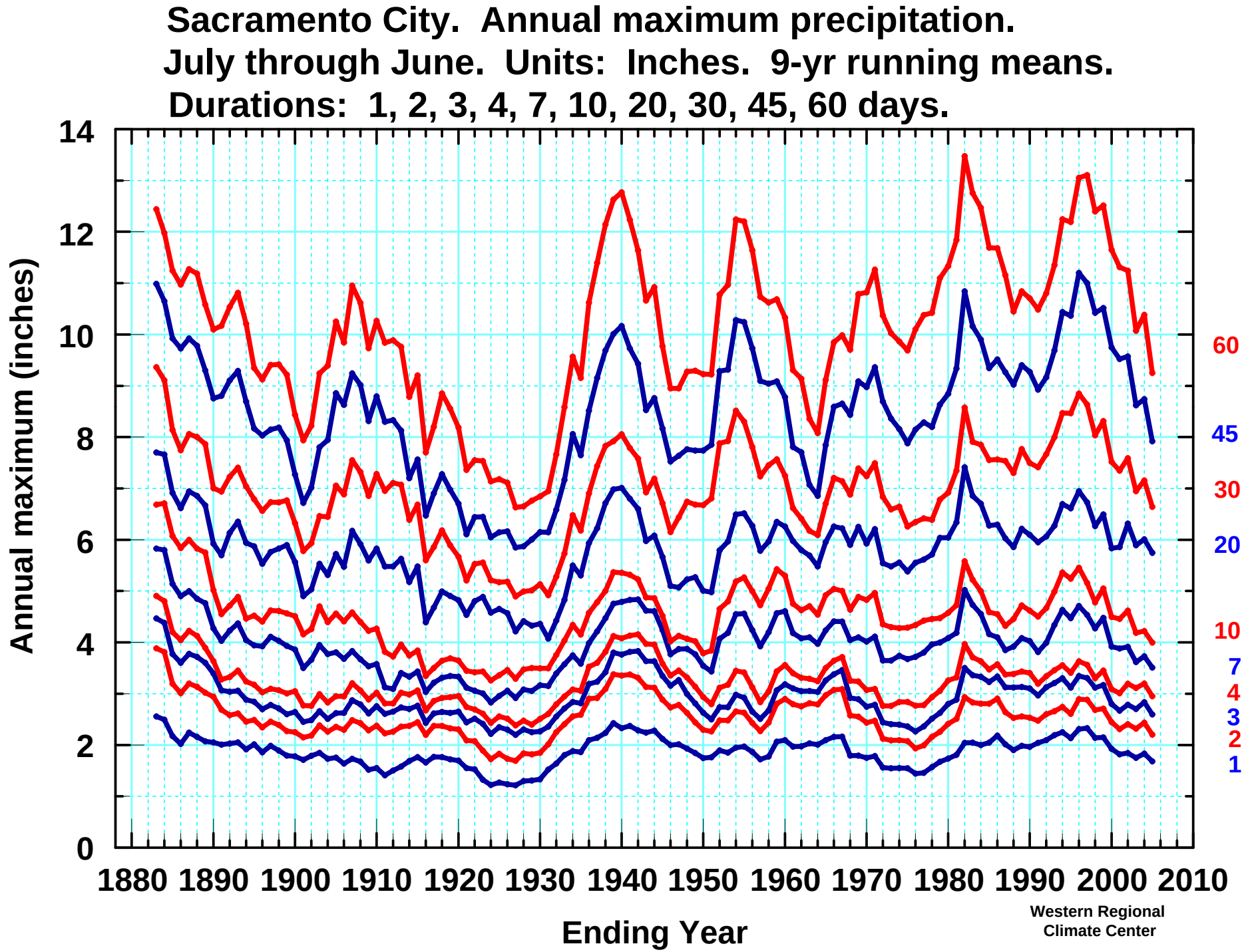

Sacramento City. Annual maximum 4-day precipitation.
July through June. Units: Inches.
Red: Annual values. Blue: 9-year running mean.
Annual 4-day max (in)
10
9
8
7
6
5
4
3
2
1
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Ending Year
Western Regional
Climate Center


Sacramento City. Annual maximum 10-day precipitation.
July through June. Units: Inches.
Red: Annual values. Blue: 9-year running mean.
Annual 10-day max (in)
0
2
4
6
8
10
12
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Ending Year
Western Regional
Climate Center


Sacramento City. Annual maximum 20-day precipitation.
July through June. Units: Inches.
Red: Annual values. Blue: 9-year running mean.
Annual 20-day max (in)
0
2
4
6
8
10
12
14
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Ending Year
Western Regional
Climate Center


Sacramento City. Annual maximum 30-day precipitation.
July through June. Units: Inches.
Red: Annual values. Blue: 9-year running mean.
Annual 30-day max (in)
16
14
12
10
8
6
4
2
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Ending Year
Western Regional
Climate Center


Sacramento City. Annual maximum 60-day precipitation.
July through June. Units: Inches.
Red: Annual values. Blue: 9-year running mean.
Annual 60-day max (in)
0
2
4
6
8
10
12
14
16
18
20
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Ending Year
Western Regional
Climate Center


Sacramento City. Annual maximum precipitation.
July through June. Units: Inches. 9-yr running means.
Durations: 1, 2, 3, 4, 7, 10, 20, 30, 45, 60 days.
Annual maximum (inches)
0
2
4
6
8
10
12
14
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Ending Year
60
45
30
20
10
7
4
3
2
1
Western Regional
Climate Center

Stationarity

There does not seem to be a uniform meaning for this word

Often used in a statistical sense

Values that are i.i.d.

independent and identically distributed

- each new event independent of the last
- always drawn from the same statistical distribution(s)

In a physical sense

The causal mechanisms in the physical world (that generate the statistics) continue to occur, and to interact with each other, in approximately the same manner, over the time period for which stationarity is claimed.

However, in the physical world, the temporal characteristics of physical causation are constantly changing, all the time, on all time scales

Stationarity concept must contain embedded implicit time scales

The climate system as an operator

y = f(x), where x is input, operated on by f, with output y

s = H(ppt; parameters), where

ppt falls as input from sky (rain or snow) ...
... is operated on by Hydrologic system H ...
... with output s (some kind of hydrologically relevant quantity)

s could represent streamflow, lake level, groundwater status, etc

H
- is not linear in ppt
- is sometimes simple, usually very complex, often extremely complex
- is dependent on many parameters representing state of system
  - Some of these themselves depend on the climate system (feedbacks)
  - Some of these are externally manipulated (e.g., human activities)
- could be natural (catchment, basin, major river system, lake, etc)
- need not be "natural" (roof, parking lot, tailings pond, alfalfa field, etc)
- acts as a kind of complex time filter

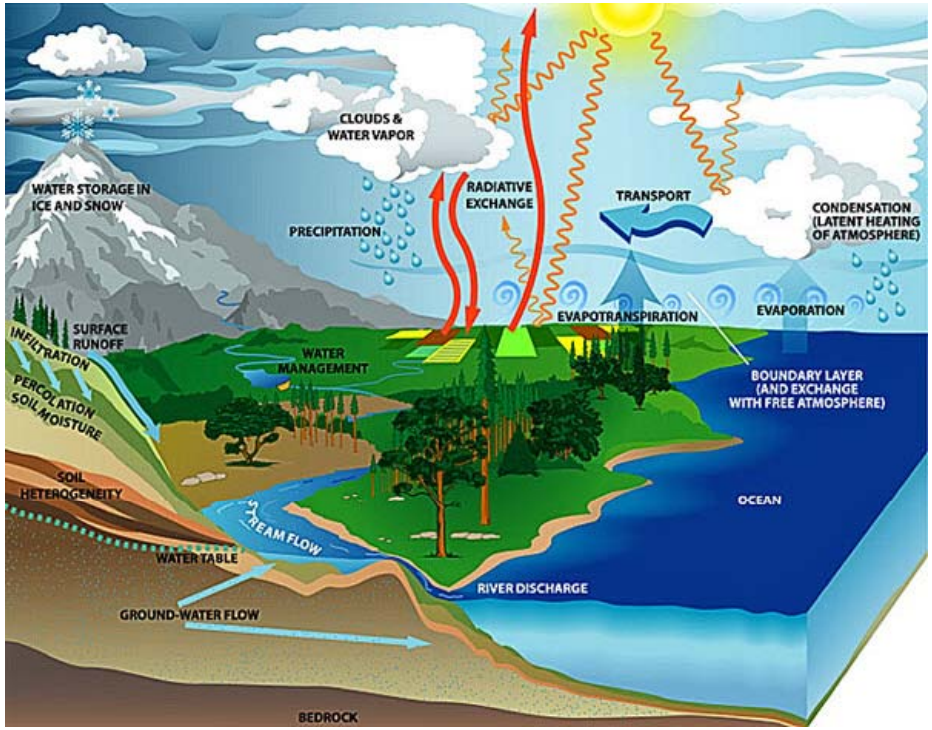
Variability in output s may result from variability in input ppt <u>or</u> in H <u>or</u> both
That is, nonstationarity in s could result from <u>driver</u> or <u>system</u> nonstationarity

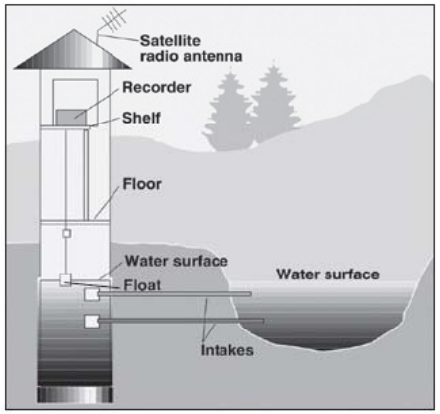
Rarity of input ppt need not produce same rarity in output s
25 year precipitation event need not produce 25 year hydro event

ppt

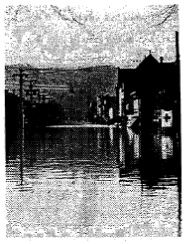
H

s


CLOUDS & WATER VAPOR
WATER STORAGE IN ICE AND SNOW
PRECIPITATION
RADIATIVE EXCHANGE
TRANSPORT
CONDENSATION (LATENT HEATING OF ATMOSPHERE)
EVAPOTRANSPIRATION
EVAPORATION
SURFACE RUNOFF
INFILTRATION
PERCOLATION
SOIL MOISTURE
WATER MANAGEMENT
BOUNDARY LAYER (AND EXCHANGE WITH FREE ATMOSPHERE)
SOIL HETEROGENEITY
OCEAN
STREAM FLOW
WATER TABLE
RIVER DISCHARGE
GROUND-WATER FLOW
BEDROCK


Satellite radio antenna
Recorder
Shelf
Floor
Water surface
Float
Water surface
Intakes

USGS 09413700 VIRGIN RV ABV THE NARROWS NR LITTLEFIELD, AZ
Discharge, cubic feet per second
30000
20000
10000
1000
100
70
Dec 16 2010
Dec 18 2010
Dec 20 2010
Dec 22 2010
Dec 24 2010
Dec 26 2010
Dec 28 2010
Dec 30 2010
---- Provisional Data Subject to Revision ----
Median daily statistic (10 years)
Discharge



Guidelines For Determining

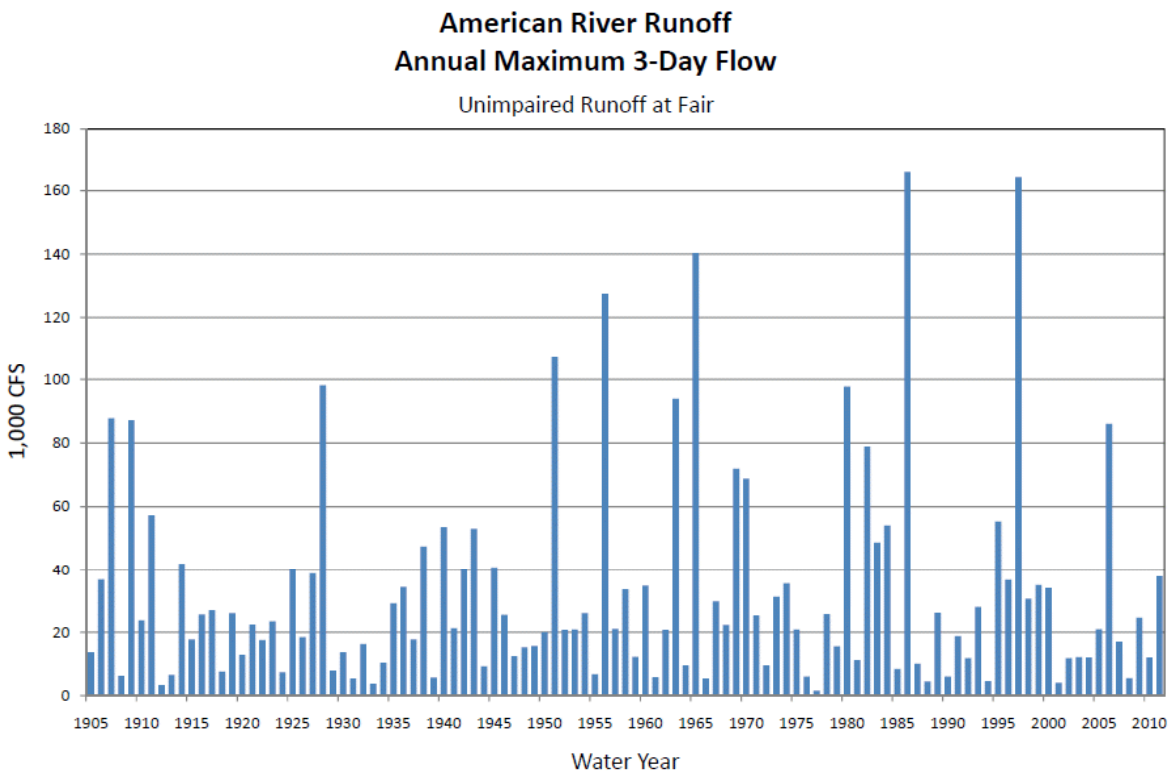
Flood Flow Frequency

Bulletin #17B
of the
Hydrology Subcommittee

Revised September 1981
Editorial Corrections March 1982

INTERAGENCY ADVISORY COMMITT
ON WATER DATA

U.S. Department of the Interior
Geological Survey
Office of Water Data Coordination
Reston, Virginia 22092



National Research Council 1999

Updated 2010 Courtesy CDWR

Mike Anderson

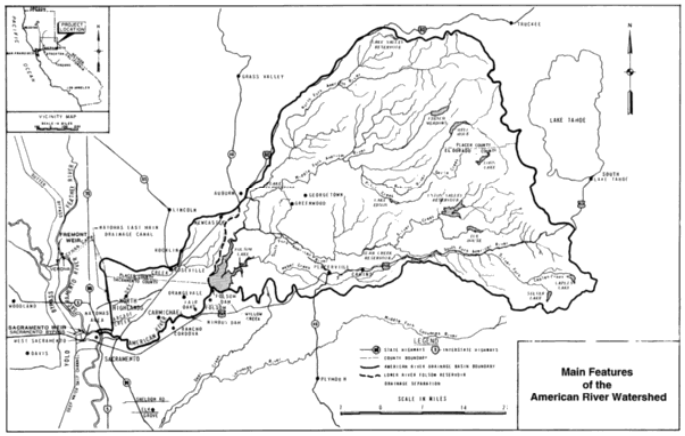
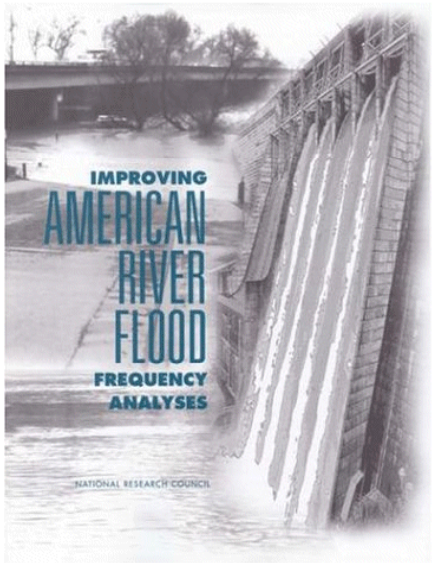
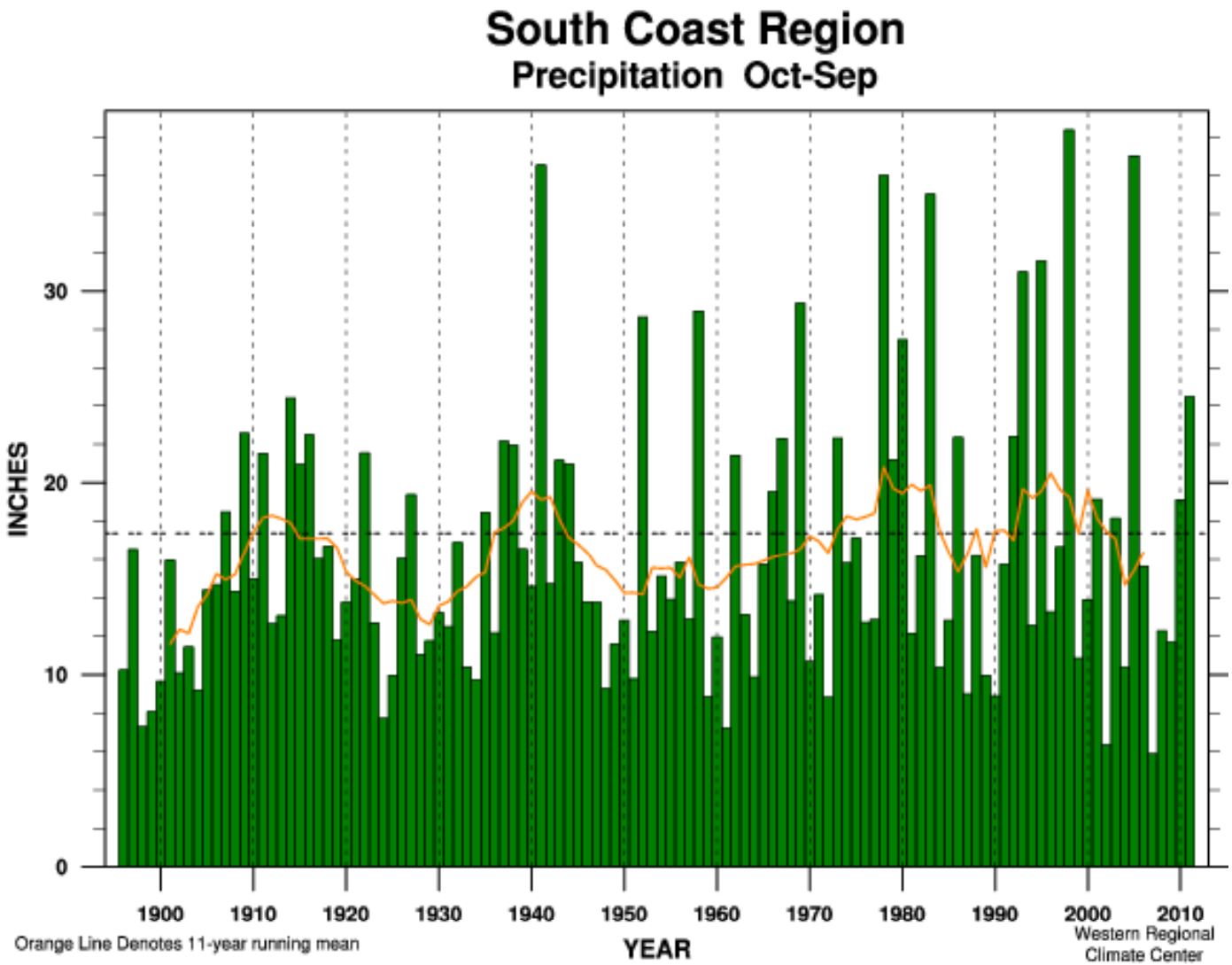


FIGURE 1.1 Main features of the American River watershed. SOURCE: Sacramento District, USACE, 1991.



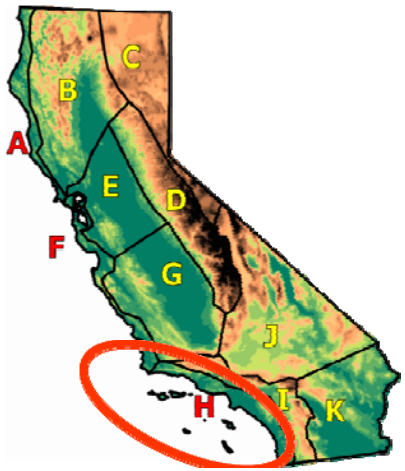


Linear Trend 1895-present	+ 3.76 ± 3.76 in.	(+ 21 ± 21%) per 100 yr	
Linear Trend 1949-present	+ 4.08 ± 11.45 in.	(+ 23 ± 65%) per 100 yr	
Linear Trend 1975-present	- 8.08 ± 29.83 in.	(- 46 ± 171%) per 100 yr	
Wettest Year	38.39 in. (220%) in 1998		MEAN 17.38 in.
Driest Year	5.87 in. (33%) in 2007		STDEV 8.13 in.
Oct-Sep 2011	24.45 in. (140%)		RANK 105 of 116

Water Year Oct-Sep Precip

South Coastal California

1895/96 thru 2010-11



Karl and Knight, 1998. Fraction of annual total from upper 10th percentile, US Average.

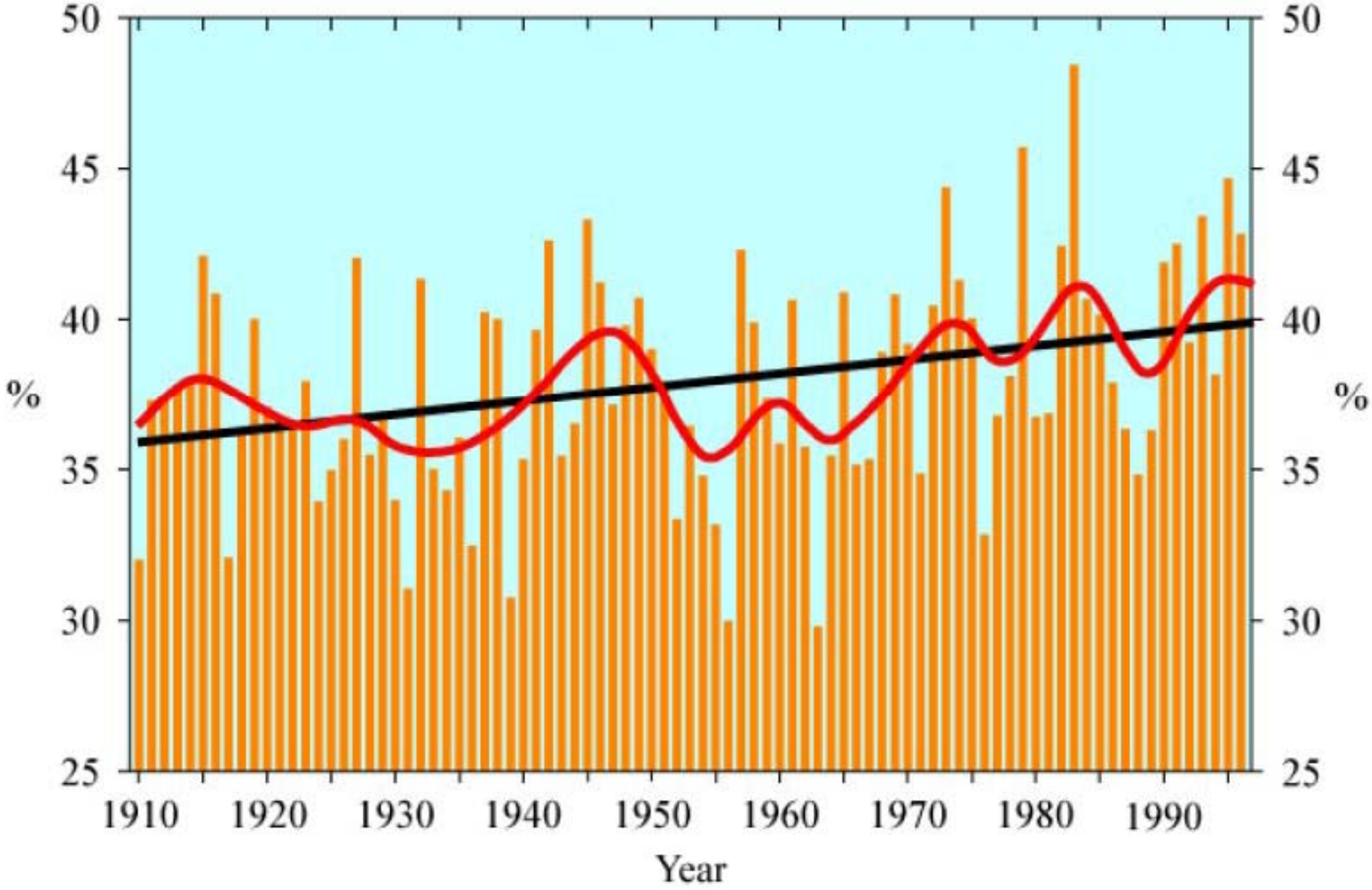


FIG. 2. Time series of the percent contribution of the upper 10 percentile of daily precipitation events to the total annual precipitation area-averaged across the United States. Smooth curve is a nine-point binomial filter, and the trend is also depicted.

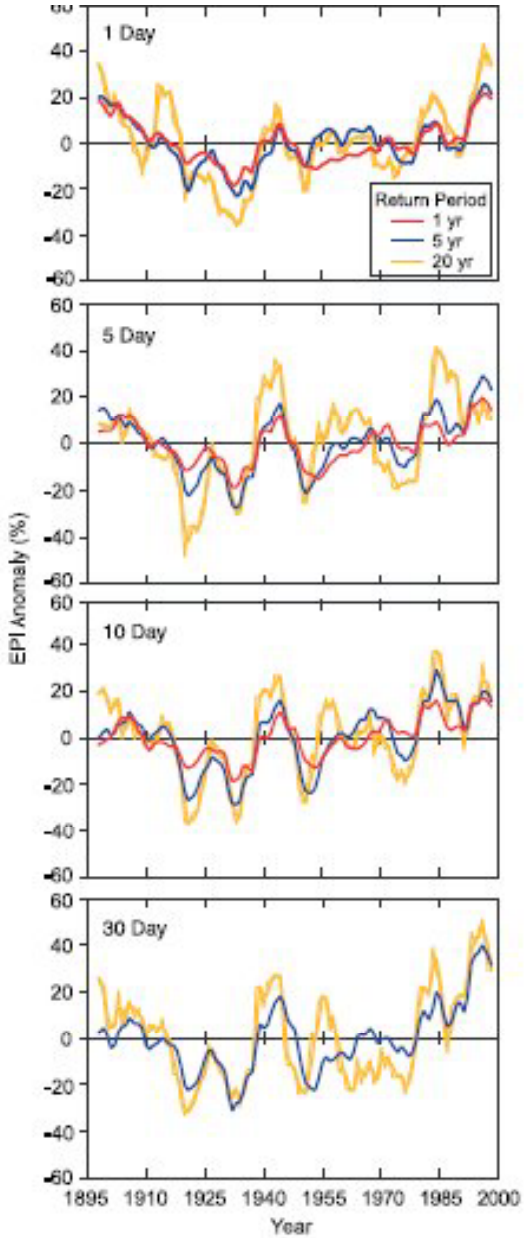


Figure 2. Time series of anomalies of the Extreme Precipitation Index, expressed in %, for various combinations of duration and return period. The time series have been smoothed with a 7-yr moving average filter. Return periods of 1 year (red), 5 years (blue), and 20 years (orange) are plotted on each graph.

1-Day

5-Day

10-Day

30-Day

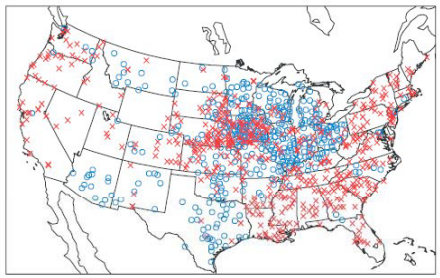


Figure 1. Location of stations with less than 10% missing daily precipitation data for 1895–2000. The symbol 'o' (in blue) indicates that long-term data were available prior to CDMP while the symbol 'x' (in red) indicates newly available long-term stations.

Extreme Precipitation Index

United States

1895-2000.

Selected durations

And

Return periods (1, 5, 20 yrs)

(Station density effects removed)

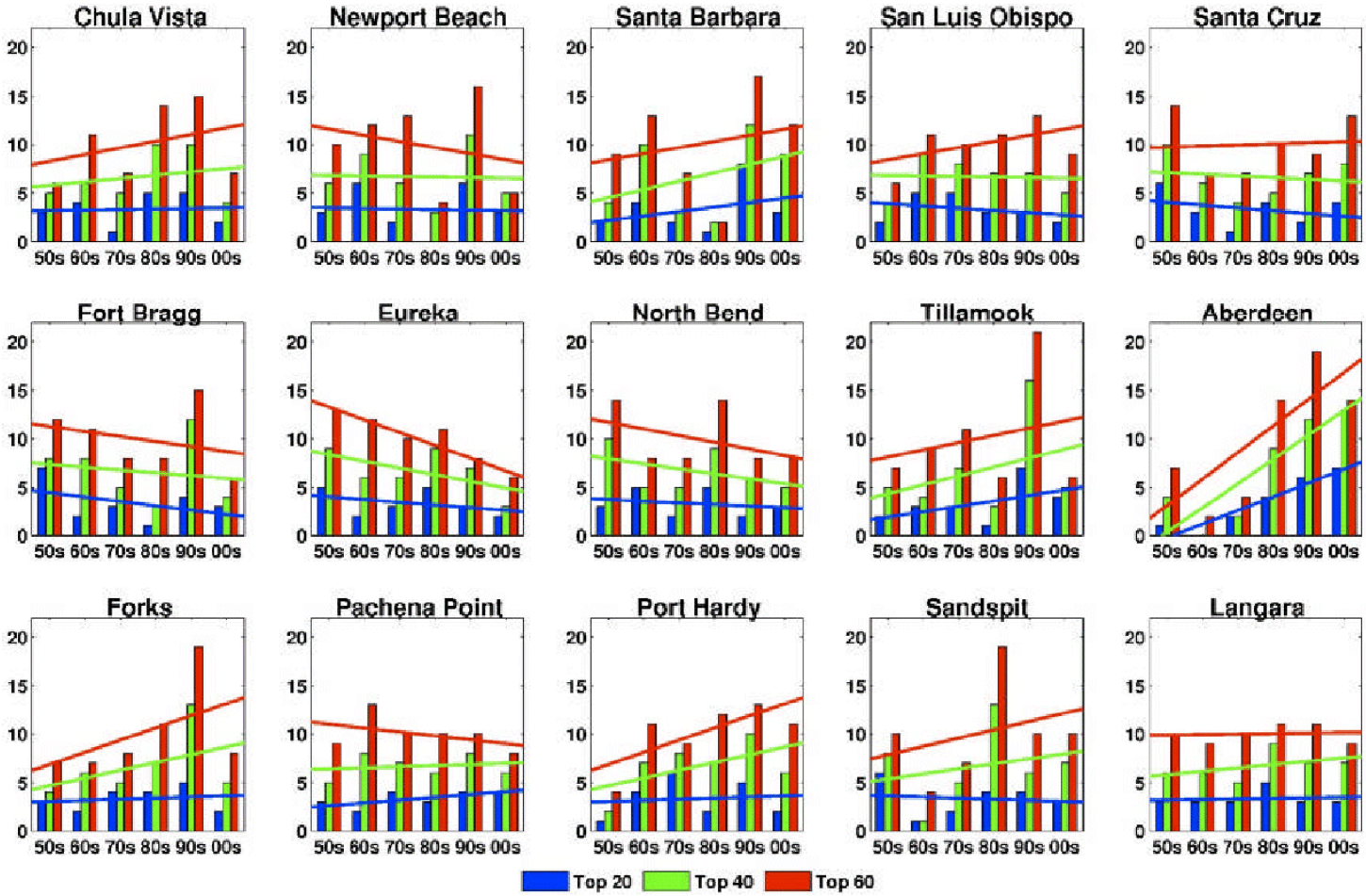
Ken E. Kunkel, Dave R. Easterling, Kelly T. Redmond, and Ken G. Hubbard, 2003.

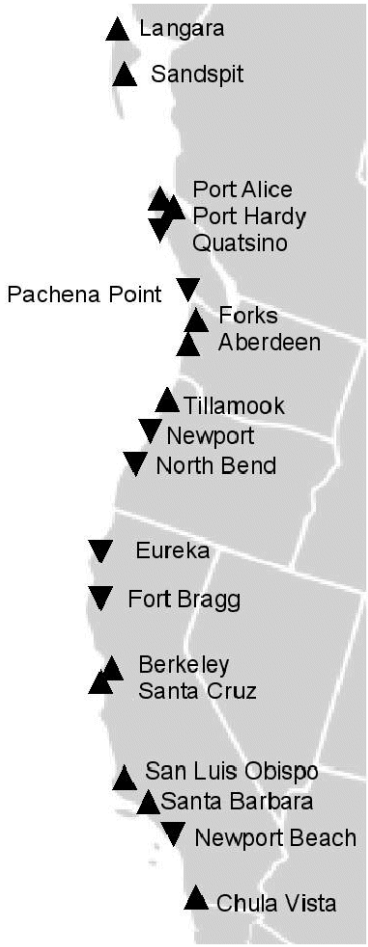
Temporal variations of extreme precipitation events in the United States: 1895-2000.

Geophysical Research Letters, 30:1717.

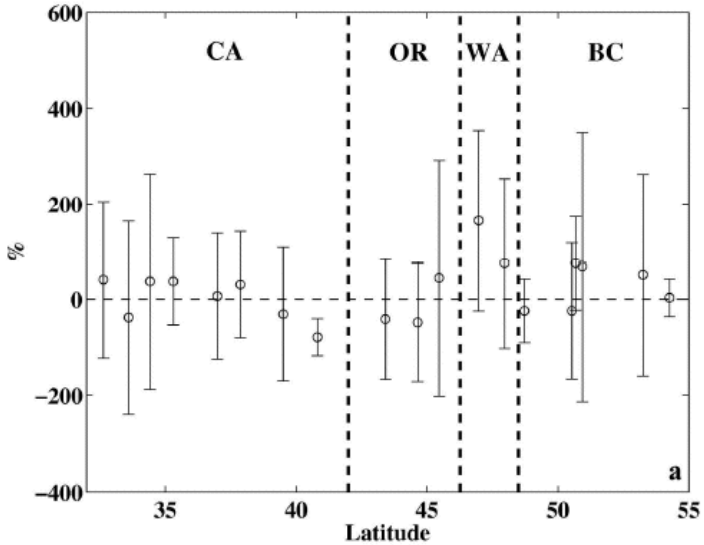
West Coast Precipitation. Annual Series of 2-Day Maximum.

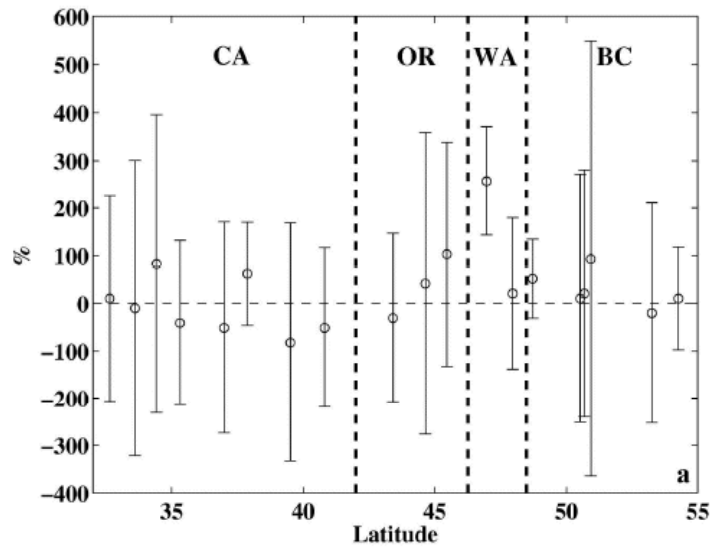
Number of events per decade. Trends 1950-2009.





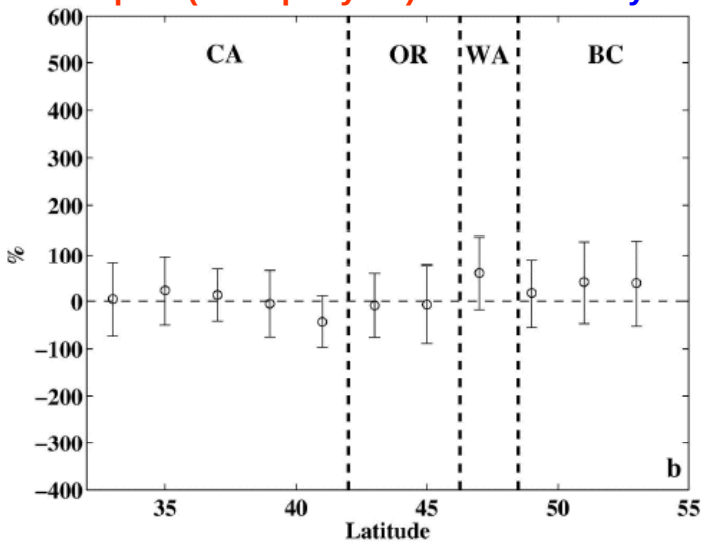
Cliff Mass, Adam Skalenakis, Michael Warner, 2011.
Extreme Precipitation over the West Coast of North America: Is There a Trend? J. Hydrometeorology. 10.1175/2010JHM1341.1

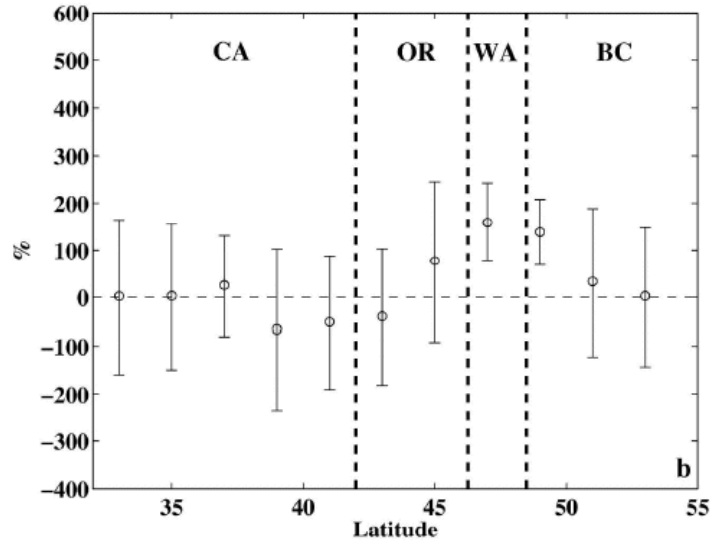




By Station

Top 60 (once per year) **Max 2-Day Precipitation Trends 1950-2009** **Top 20 (once per three years)**





By Latitude

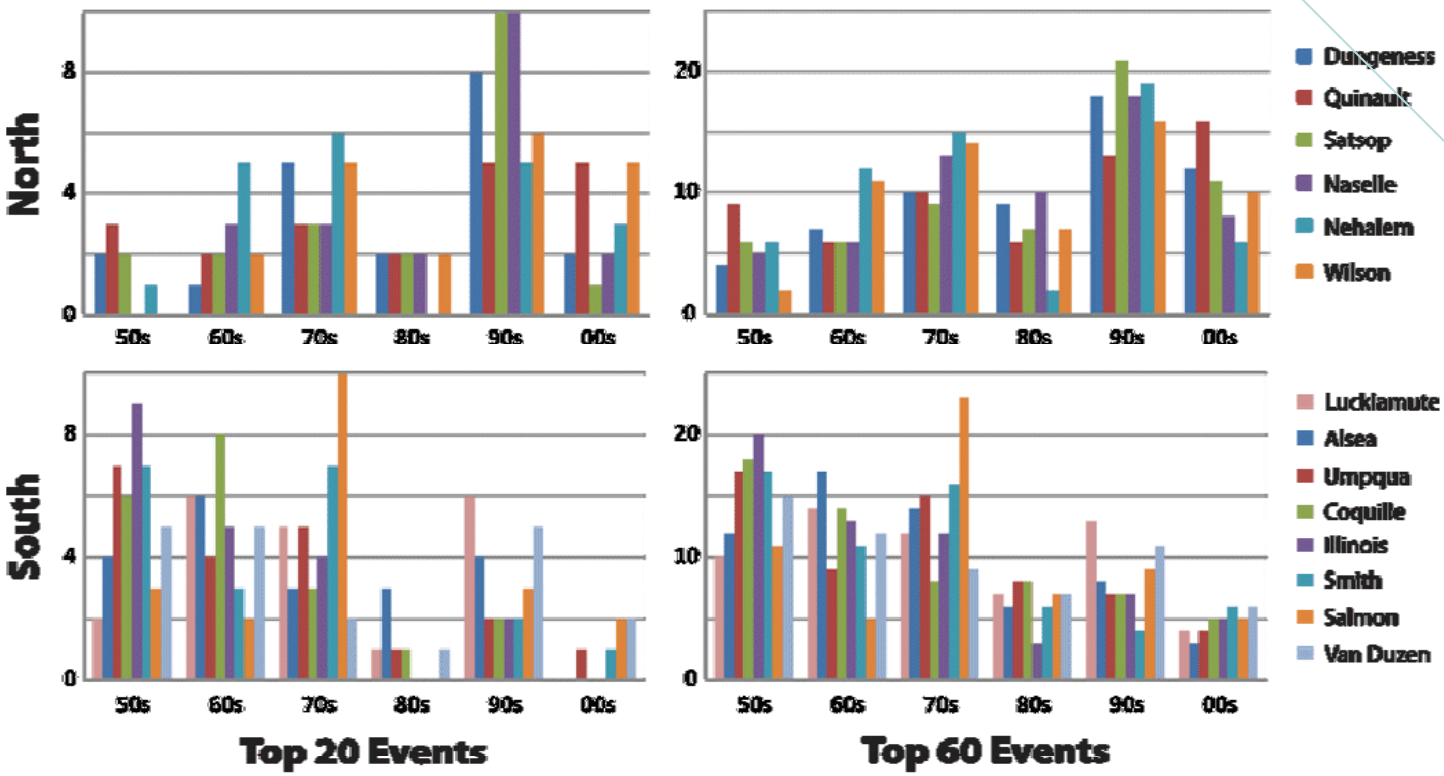
Figure 3: Sixty-year trends for the top 60 events for all stations (a) and for averages of the stations over 2° latitude bands (b). The trends are given in percent change relative to the mean over the 60-year period. The vertical dotted lines indicate the state boundaries and the brackets indicate the 95% interval derived from using formula (1).

Figure 4: Sixty-year trends for the top 20 events for all stations (a) and for averages of the stations over 2° latitude bands (b). The trends are given in percent change over the 60-yr period. The vertical dotted lines indicate the state boundaries and the brackets indicate the 95% interval derived from using formula (1).

Cliff Mass, Adam Skalenakis, Michael Warner, 2011.
Extreme Precipitation over the West Coast of North America: Is There a Trend? J. Hydrometeorology. 10.1175/2010JHM1341.1

West Coast Streamflow. Annual Series of 1-Day Maximum Discharges.

Number of events per decade. Trends 1950-2009.



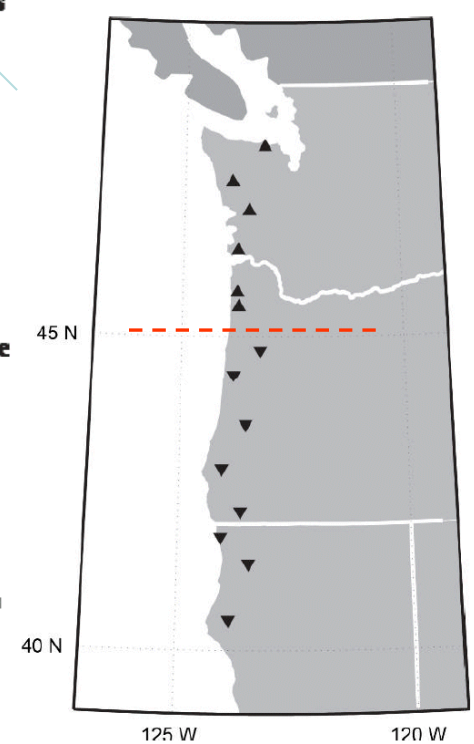


Figure 7: Decadal variation of the top 20 and 60 average daily discharges for 1950-2009 for unregulated rivers north and south of 45°N latitude.

Cliff Mass, Adam Skalenakis, Michael Warner, 2011.
Extreme Precipitation over the West Coast of North America: Is There a Trend? J. Hydrometeorology. 10.1175/2010JHM1341.1

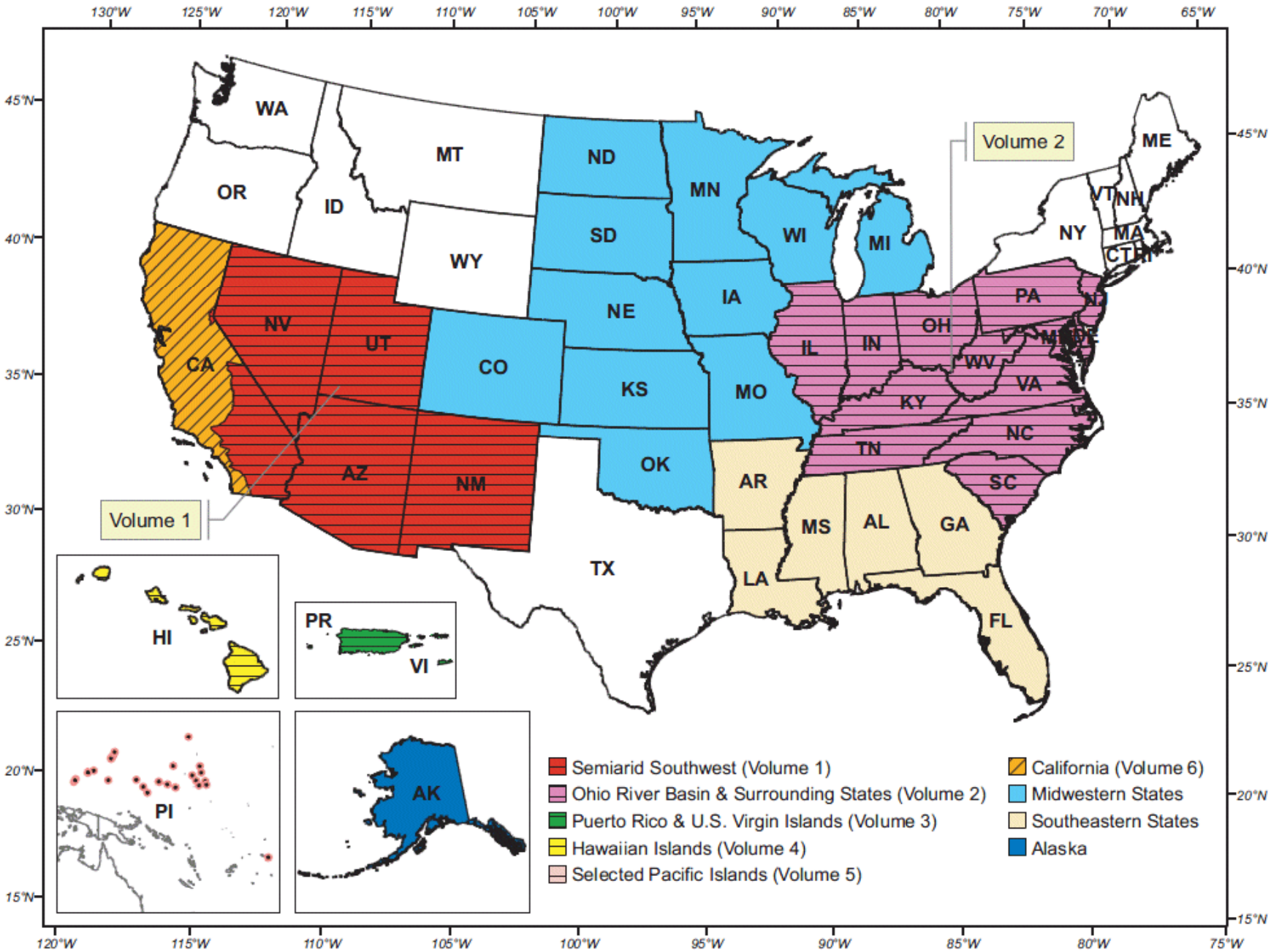


FIGURE 1. NOAA Atlas 14 Volume Domains.

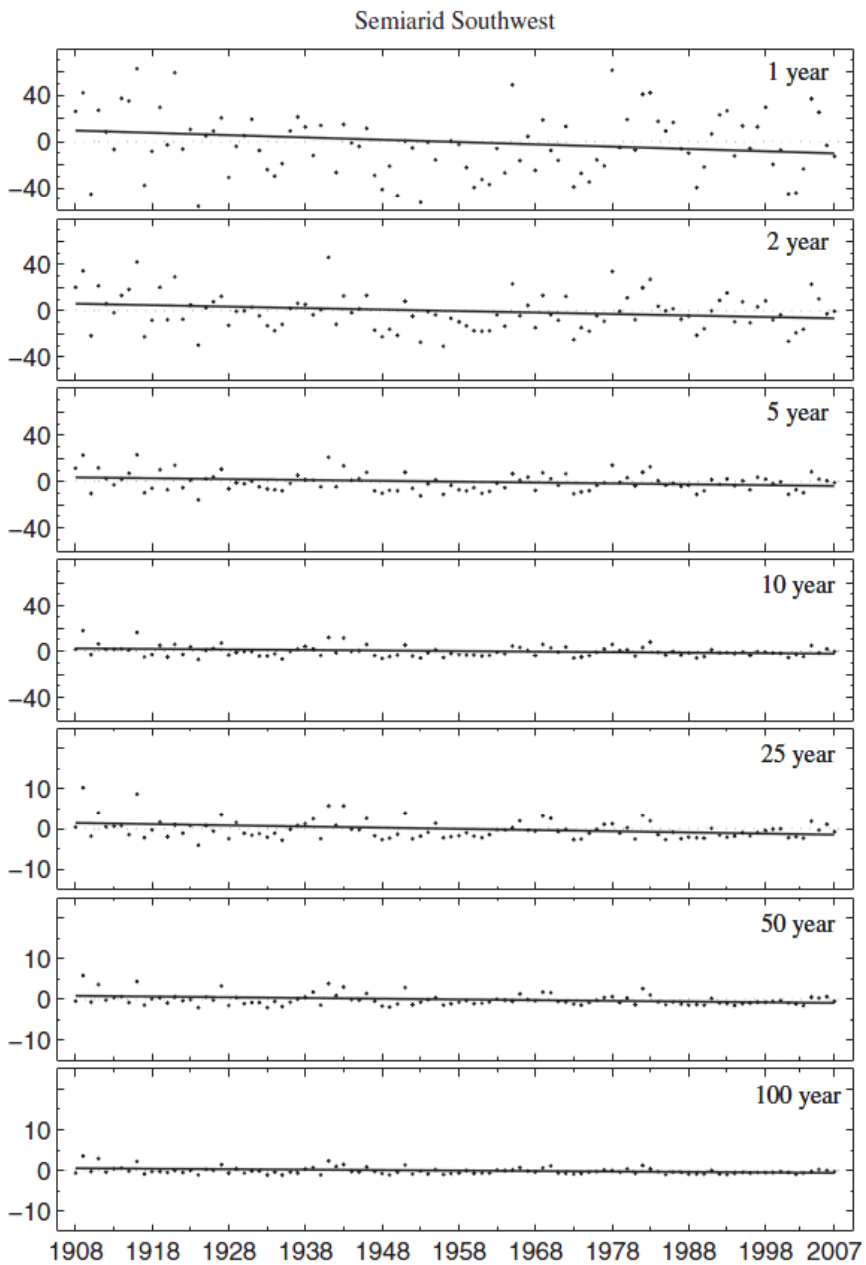


FIGURE 3. Semiarid Southwest One-Day Exceedances. Similar to Figure 2, except the period covered is 1908-2007. Similar results were obtained at other multiday durations.

1 - Year

2 - Year

5 - Year

10 - Year

25 - Year

50 - Year

100 - Year

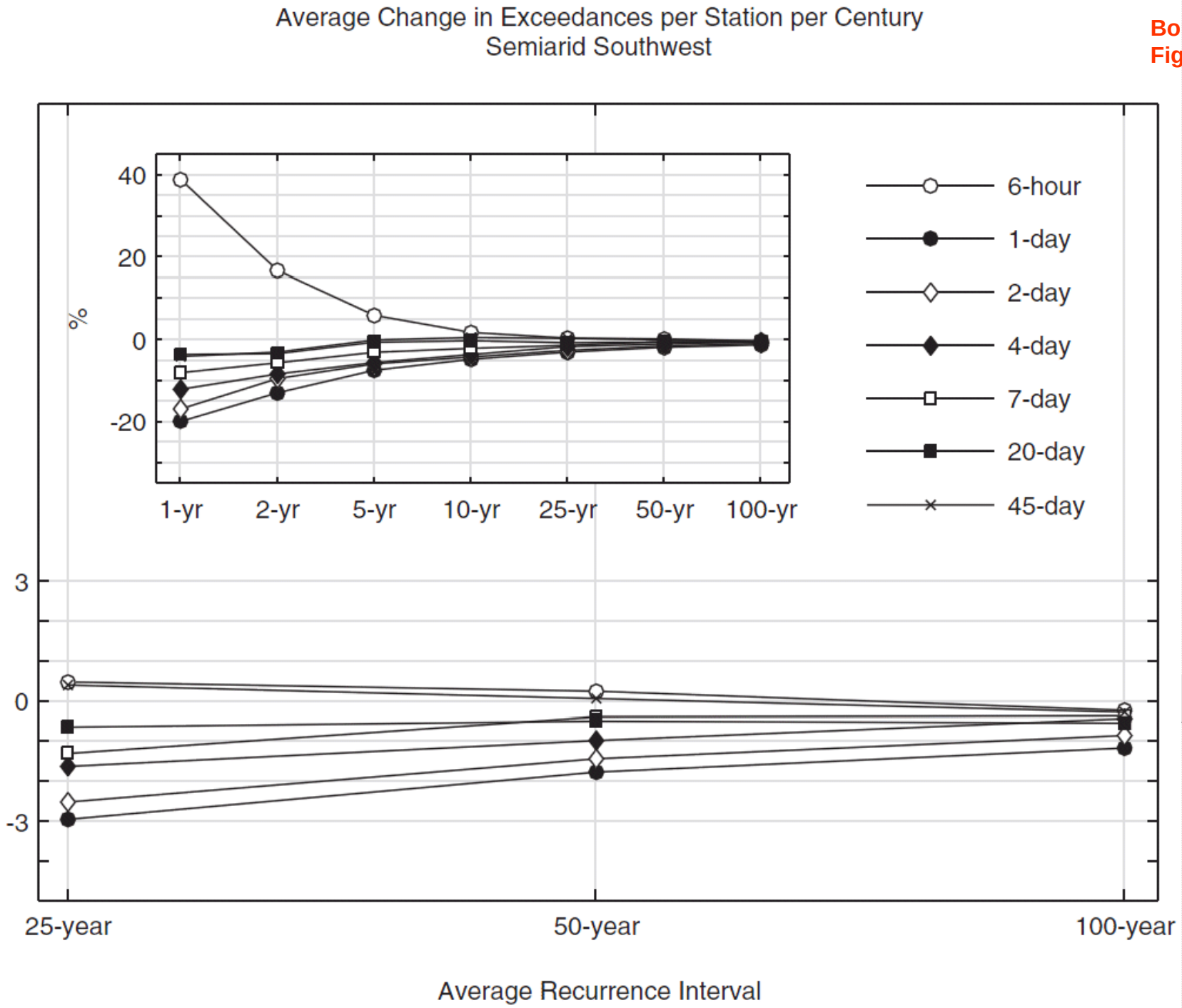
Trends in 1-Day Exceedance Values for Precipitation.

Southwest USA.

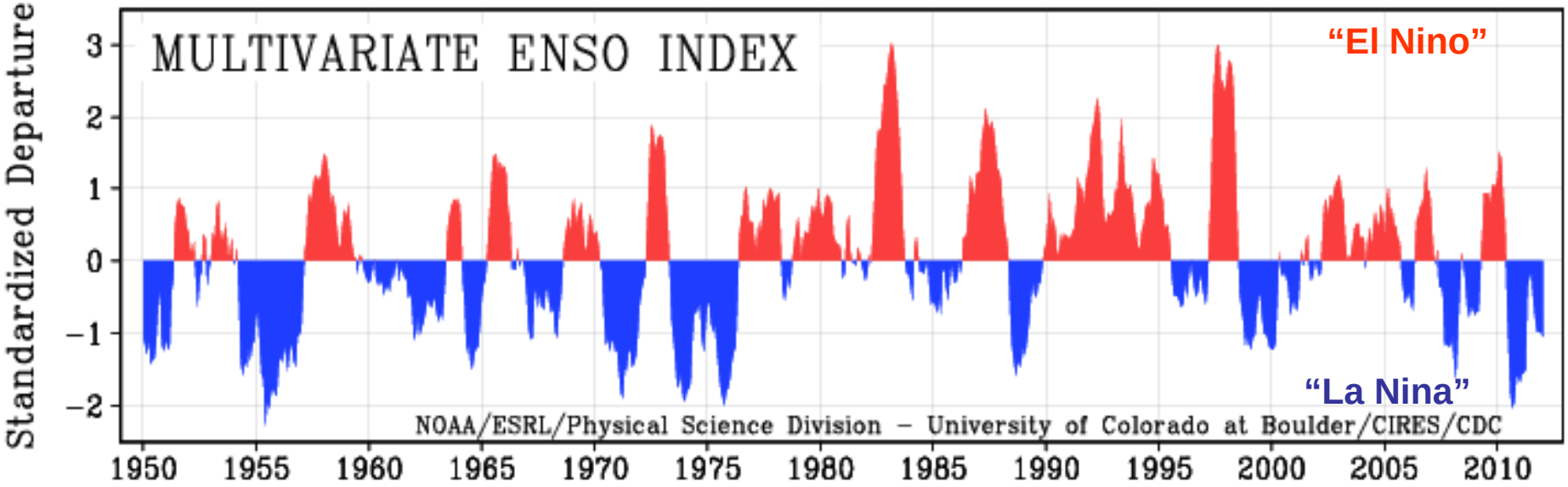
1908-2007.

Geoffrey M Bonnin, Kazungu Maitaria, Michael Yekta. 2011. Trends in Rainfall Exceedances in the Observed Record in Selected Areas of the United States. Journal of the American Water Resources Association, 47(6), 1173-1182.

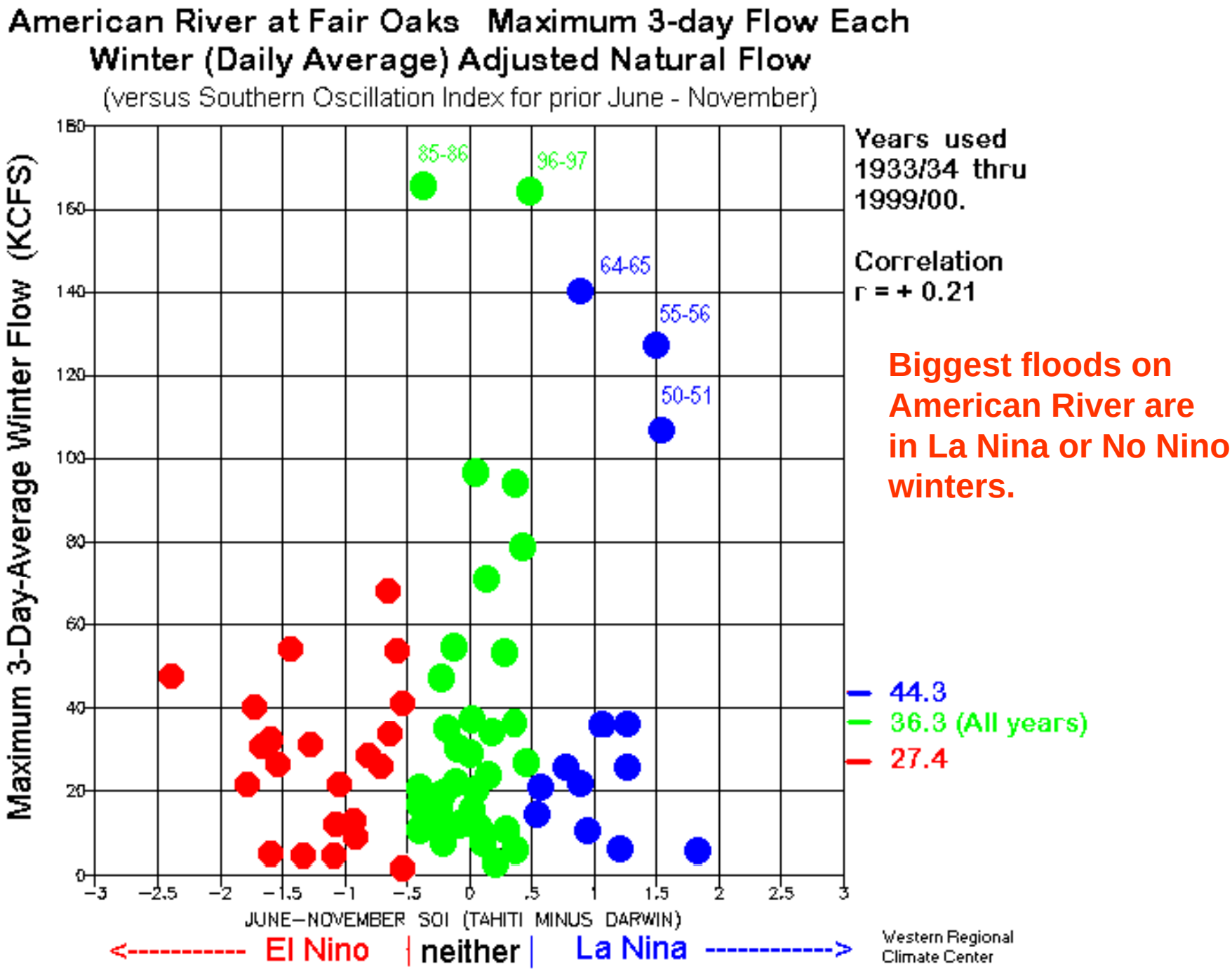
Bonnin et al, 2011.
Figure 6.



Through January 2012



NOAA ESRL ("CDC"), Wolter and Timlin


American River at Fair Oaks Maximum 3-day Flow Each Winter (Daily Average) Adjusted Natural Flow
(versus Southern Oscillation Index for prior June - November)
Maximum 3-Day-Average Winter Flow (KCFS)
JUNE–NOVEMBER SOI (TAHITI MINUS DARWIN)
85-86
96-97
64-65
55-56
50-51
Years used 1933/34 thru 1999/00.
Correlation r = + 0.21
Biggest floods on American River are in La Nina or No Nino winters.
44.3
36.3 (All years)
27.4
<---------- El Nino | neither | La Nina ---------->
Western Regional Climate Center

HH PRESENTS
ATTACK OF LA NIÑA
A NEW SKI MOVIE BY MSP FILMS
MISSOULA, MT Wilma Theatre 10.21.11
Show: 8pm- doors @ 7pm $10.00
TICKETS Gull Ski Shop / 2610 W. Broadway St. / 406.549.5603 / www.gullskishop.com
Wilma Theatre / 131 Higgins Ave. / Tickets available night of show @ door
BOZEMAN, MT Emerson Center 10.22.11
Show: 6pm- doors @ 5:30pm / 8:30pm- doors @ 8pm $10.00
TICKETS Emerson Cultural Center / 111 S. Grand Ave. / Tickets available night of show @ door
Holly Hanson Bozeman / 30 W. Main St. / 406.586.0503
skimovie.com

Water **2011**, *3*, 445-478; doi:10.3390/w3020445

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water

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Article

Atmospheric Rivers, Floods and the Water Resources of California

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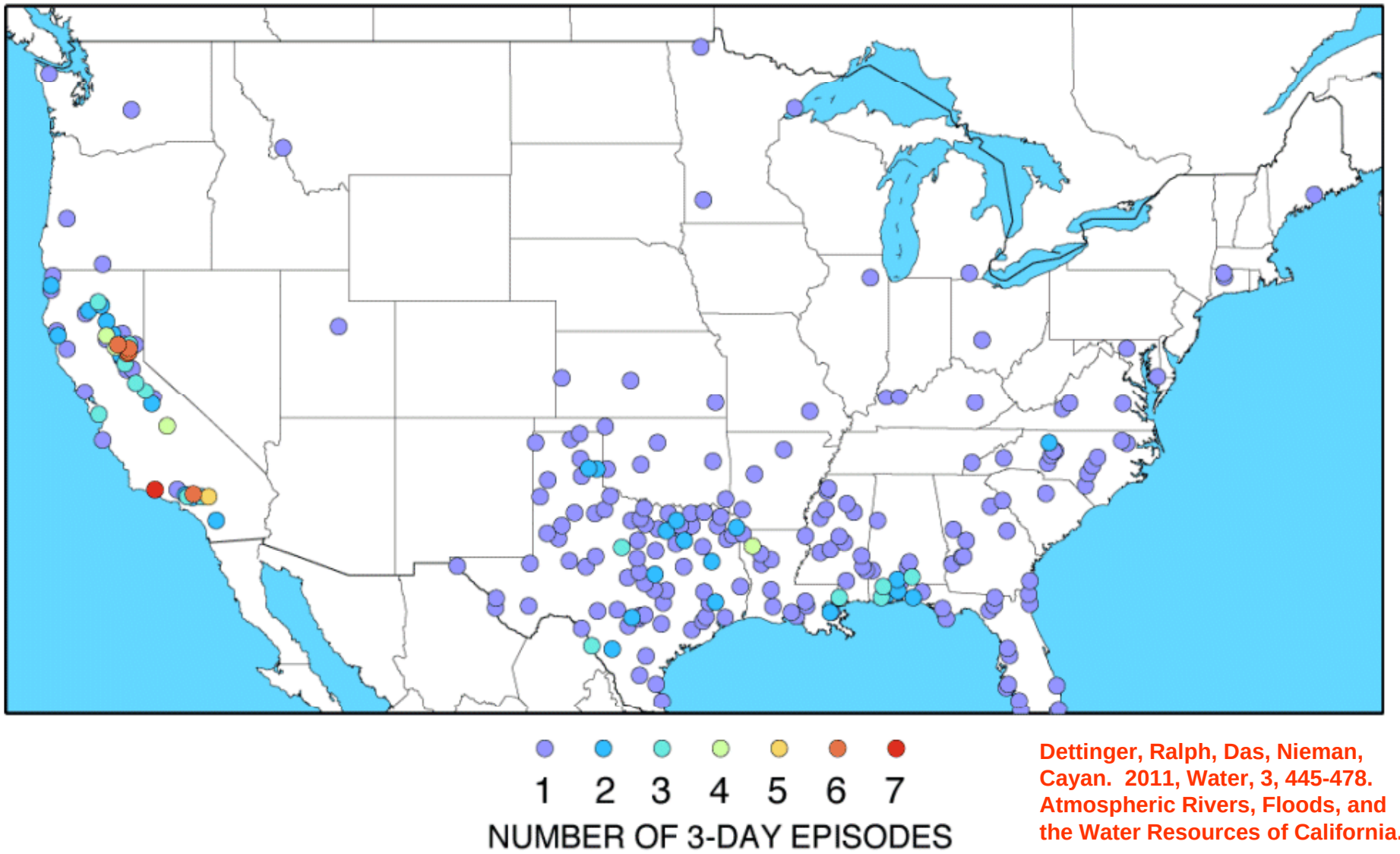
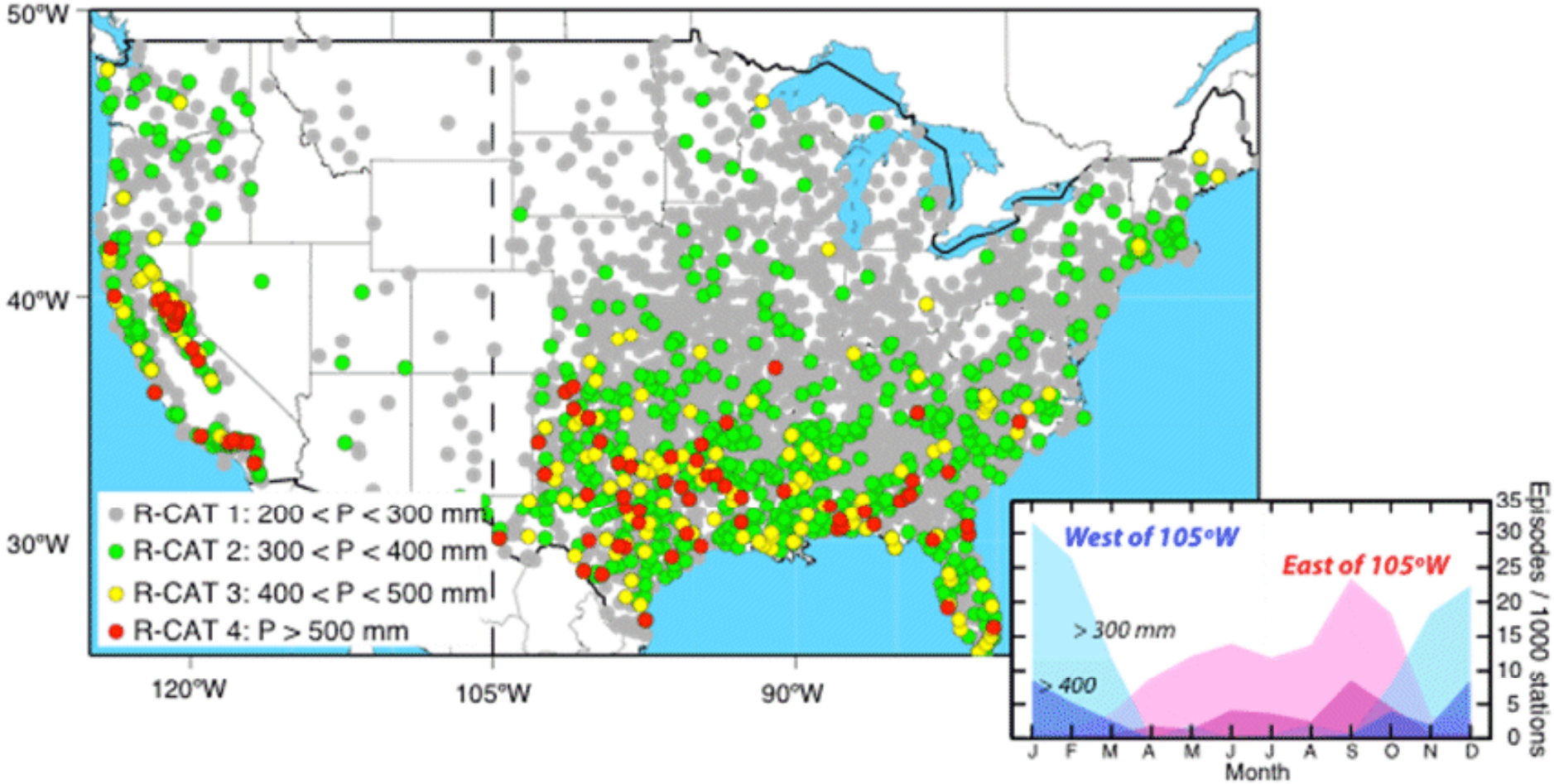
Number of 3-day episodes with at least 16 inches of precipitation. 1950-2008.

Figure 4. Numbers of reported occasions of (nonoverlapping) 3-day precipitation totals at cooperative weather stations that exceeded 40 cm, from 1950–2008.



Dettinger, Ralph, Das, Nieman, Cayan. 2011, Water, 3, 445-478. Atmospheric Rivers, Floods, and the Water Resources of California.

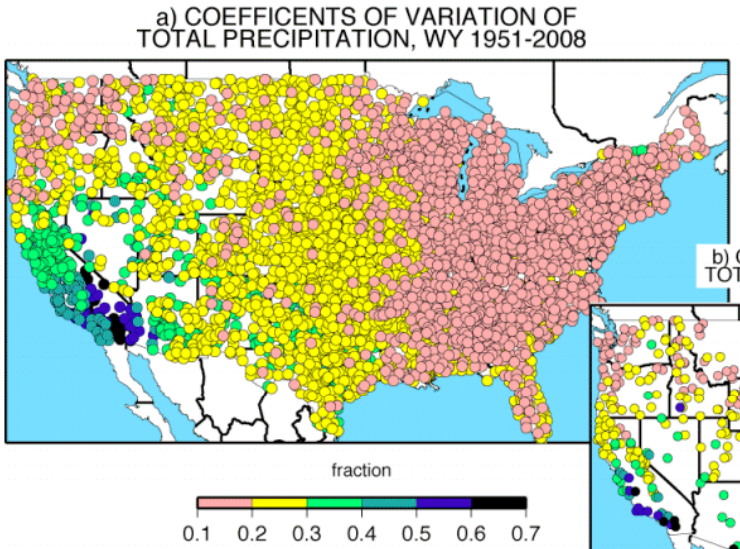
MAXIMUM 3-DAY PRECIPITATION TOTALS AT US COOP STATIONS, 1950-2008



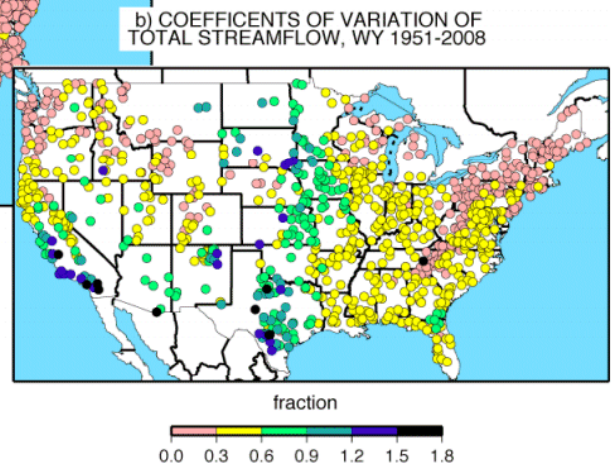
Dave Reynolds, F. Martin Ralph, and Michael Dettinger. Categories for Comparison and Communication of Extreme Precipitation Storm Totals across the U.S.: Potential Application to NWS Hydrologic Operations.

Figure 2. Coefficients of variation of water-year **(a)** precipitation and **(b)** streamflow totals at long-term monitoring stations across the conterminous US, from water year 1951–2008, along with **(c)** tallies of the minimum number of wet days per year, on average, that provide half of the year's precipitation in the western States.

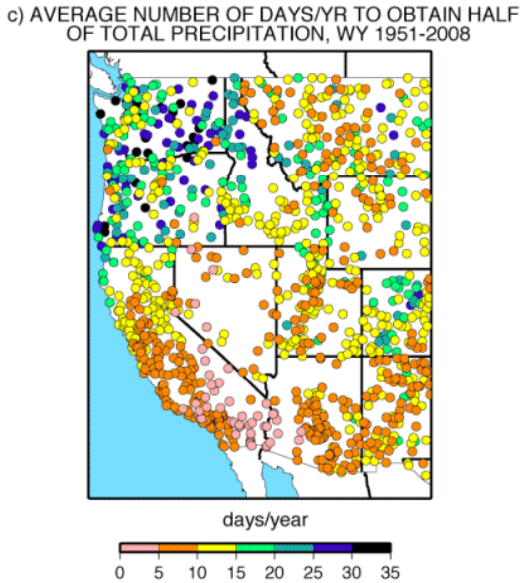
1950 - 2008



Water Year Precipitation.
Coefficient of variation.
Standard Deviation / Mean.
Shows relative variation.



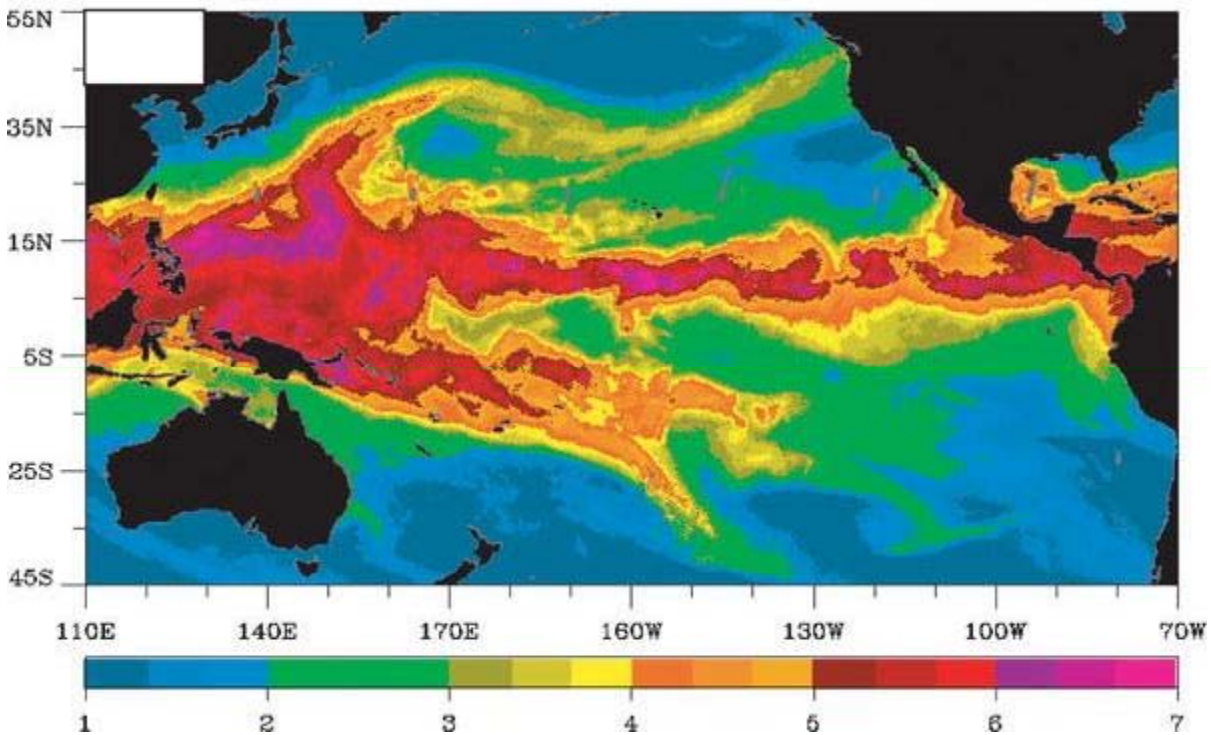
Water Year Streamflow
Coefficient of variation.
Standard Deviation / Mean.
Shows relative variation.

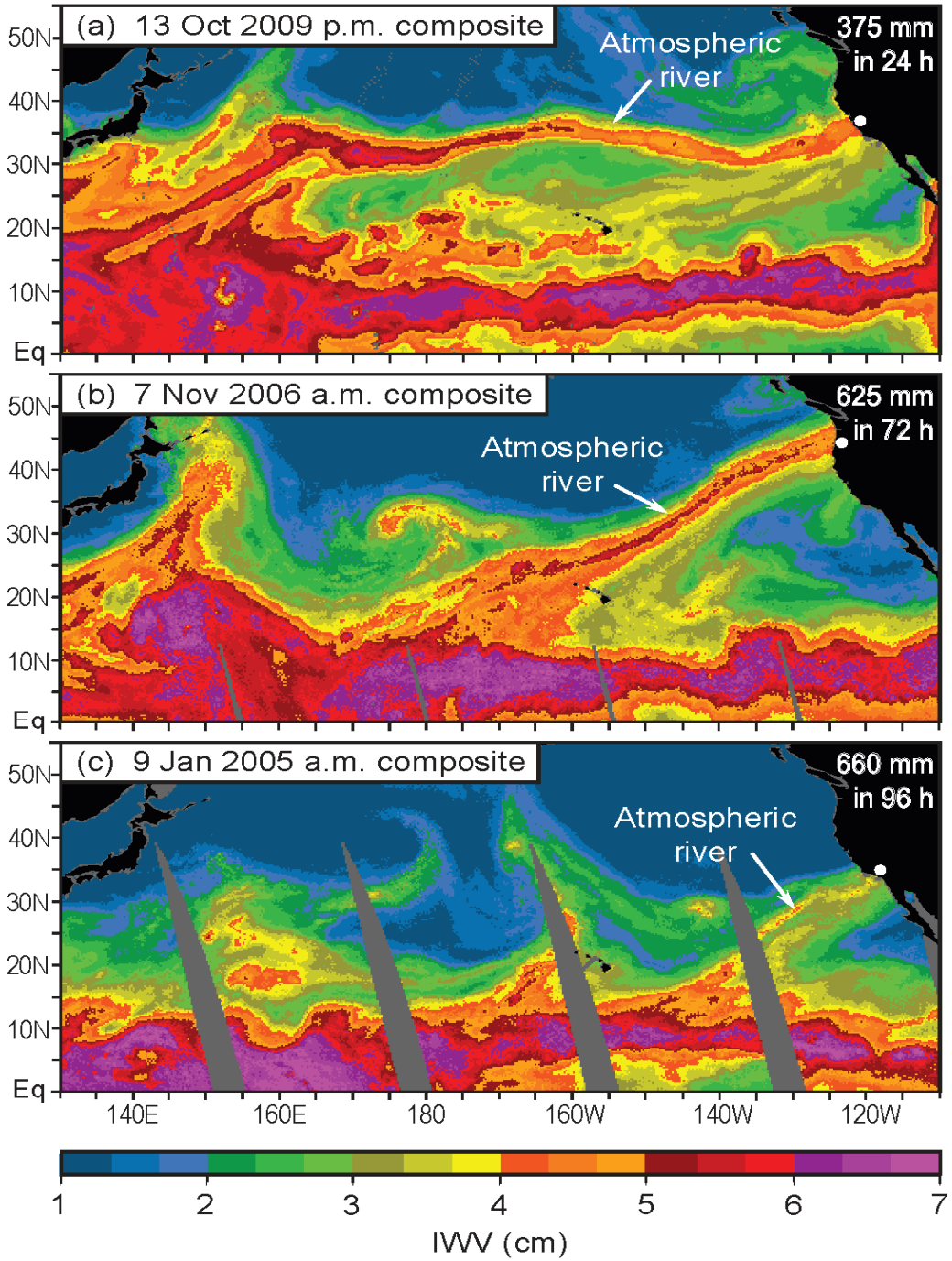


Number of days in a typical year
to obtain half of total precipitation.
Los Angeles Airport (approx 10 d):
35 days with 0.01" +
21 days with 0.10" +
8 days with 0.50" +
3 days with 1.00" +

Dettinger, Ralph, Das, Nieman, Cayan. 2011, Water, 3, 445-478. Atmospheric Rivers, Floods, and the Water Resources of California.

Atmospheric River





A Key HMT Finding:

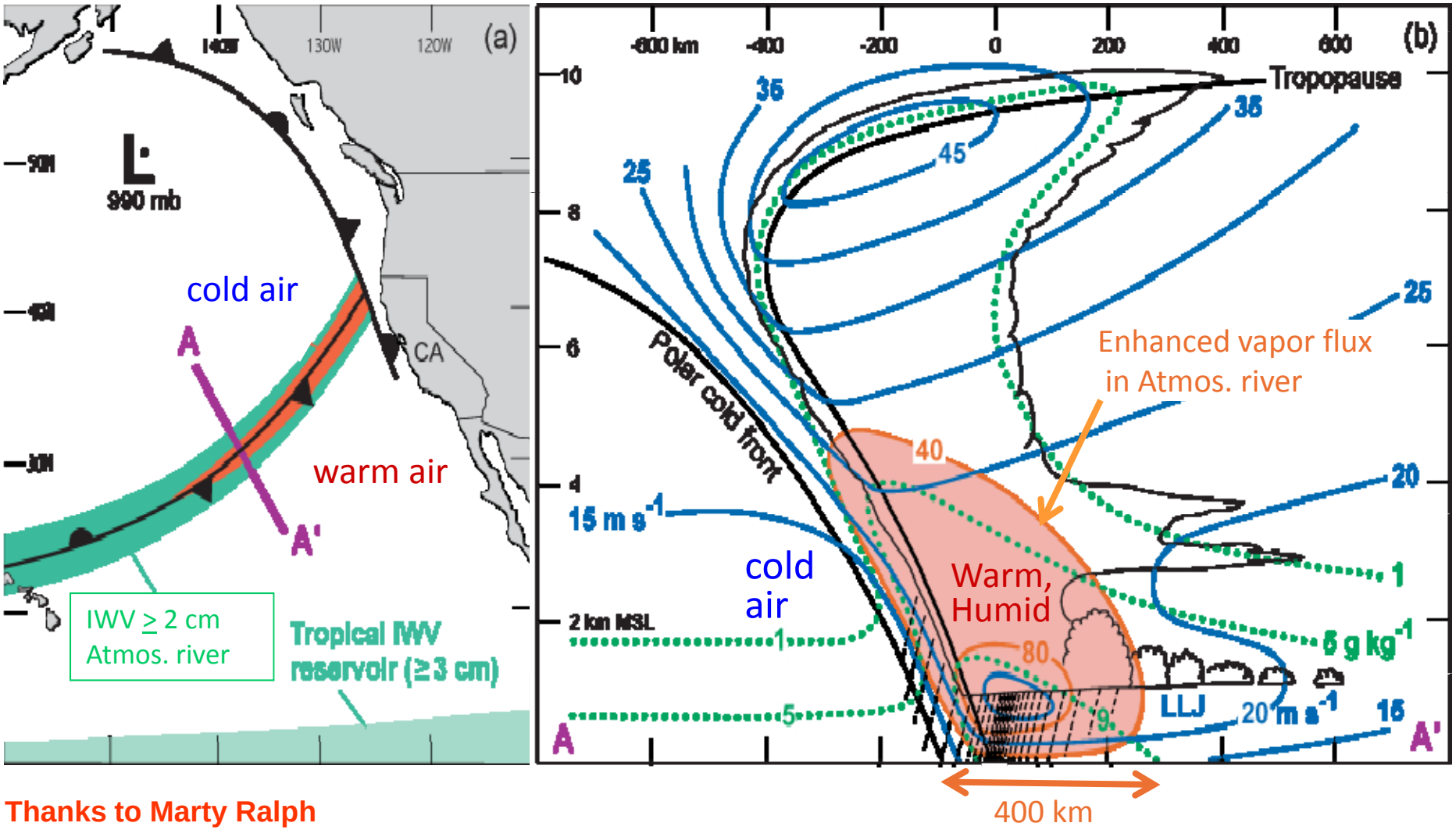
- atmospheric rivers are a key to extreme precipitation and flooding, as well as water supply and stream flow on the U.S. West Coast

Examples of AR events that produced extreme precipitation on the US West Coast, and exhibited spatial continuity with the tropical water vapor reservoir as seen in SSM/I satellite observations of IWV.

Thanks to Marty Ralph

Observational studies by Ralph et al. (2004, 2005, 2006) extend model results:

1) Long, narrow plumes of IWV >2 cm measured by SSM/I satellites considered proxies for ARs.
2) These plumes (darker green) are typically situated near the leading edge of polar cold fronts.
3) P-3 aircraft documented strong water vapor flux in a narrow (400 km-wide) AR; See section AA'.
4) Airborne data also showed 75% of the vapor flux was below 2.5 km MSL in vicinity of LLJ.



Thanks to Marty Ralph

Atmospheric River Connections

Have recently (5-10 yrs) become more widely appreciated

Most West Coast floods involve an Atmospheric River

An Atmospheric River will almost always produce at least a local flood

So far, have emphasized West Coast
- Now looking farther inland
- Also, Nashville flood

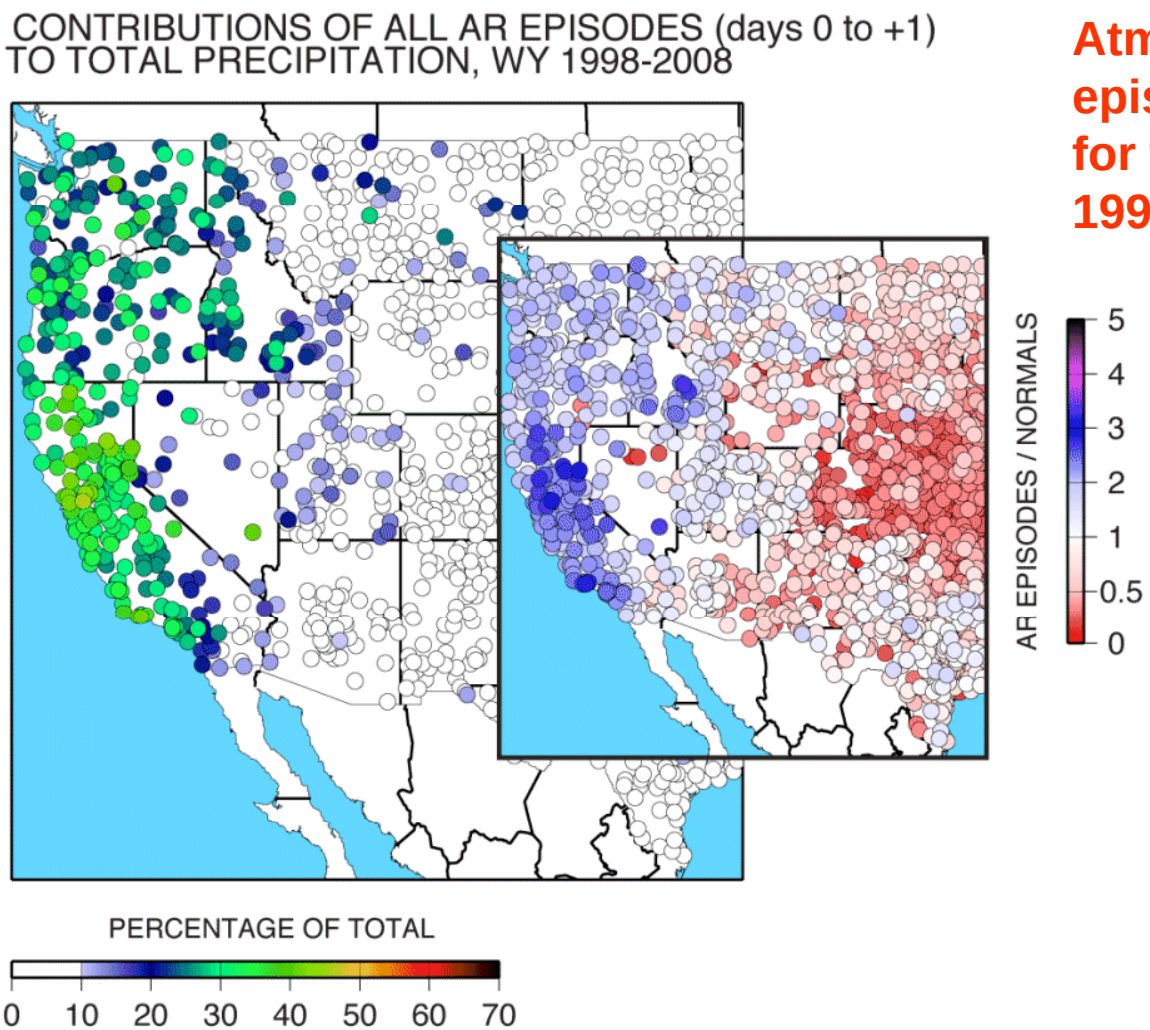
Since warm, often a Rain-on-Snow producer

Often are the difference between a drought winter and an adequate winter

<u>ARkStorm</u>
- Inspired by 1861-62 floods
  - Description
- About 6 events in the last 2000 years
  - 1805 ?
  - 1605 ?
- Scenario for a major planning effort for California
  - Average to wet setup, 1969+1d SoCal storm, 1986 CenCal storm

- Earthquake analog: "The Big One" in California meteorology

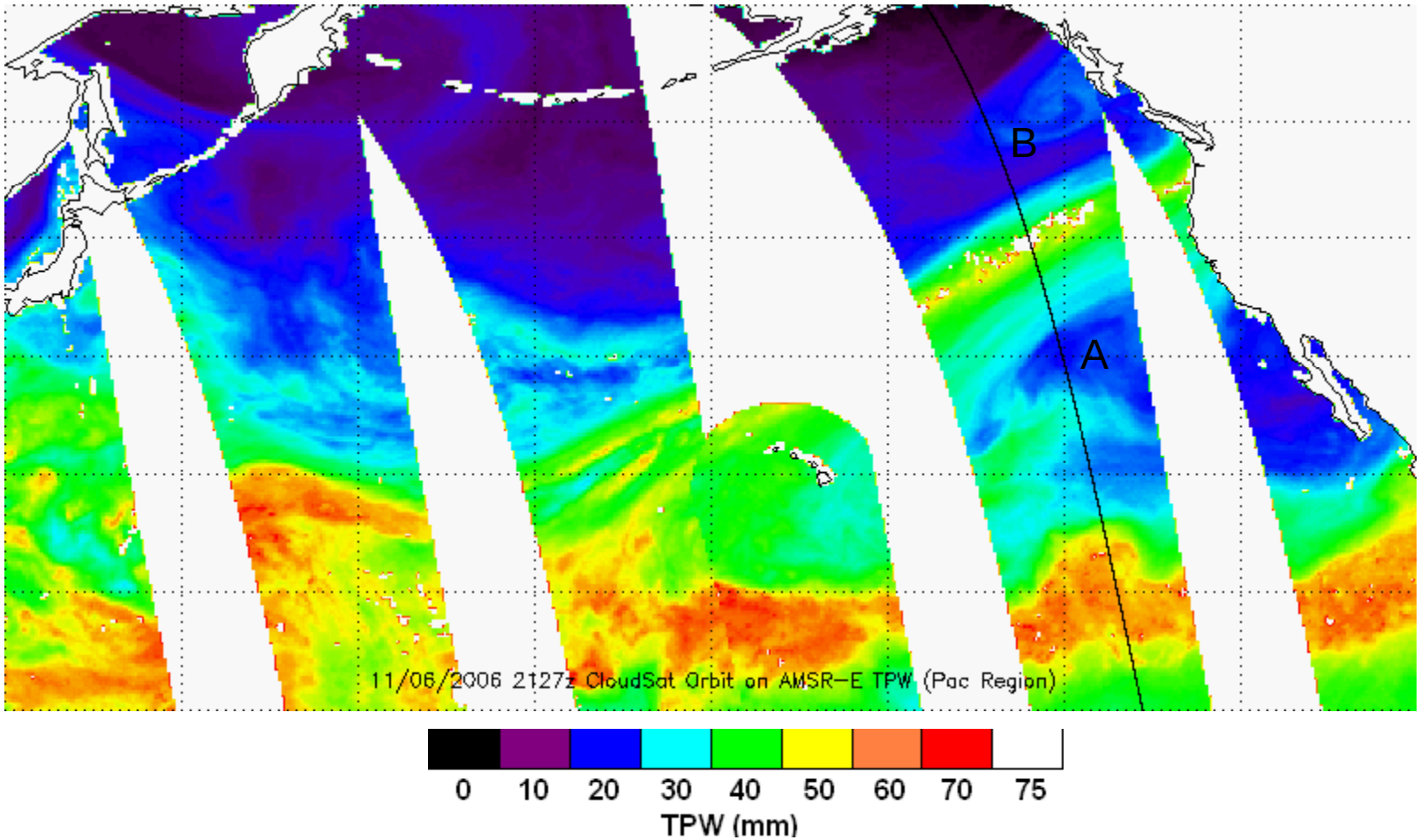
Figure 6. Contributions of precipitation during wet-season (November–April) days on which atmospheric rivers made landfall on the West Coast (based on Table 1) to overall precipitation from water year 1998 through 2008 at cooperative weather stations in the western US. Inset map shows the ratio of average precipitation on the AR days (including concurrent day and following day) to climatological means for the same combination of days. Concurrent and one following day are composited here to allow for a 1-day uncertainty between the GMT-based AR chronology and local-time cooperative precipitation observations.



Contribution of all Atmospheric River (AR) episodes to total precipitation for the water year. 1998 - 2008.

Dettinger, Ralph, Das, Nieman, Cayan. 2011, Water, 3, 445-478. Atmospheric Rivers, Floods, and the Water Resources of California.

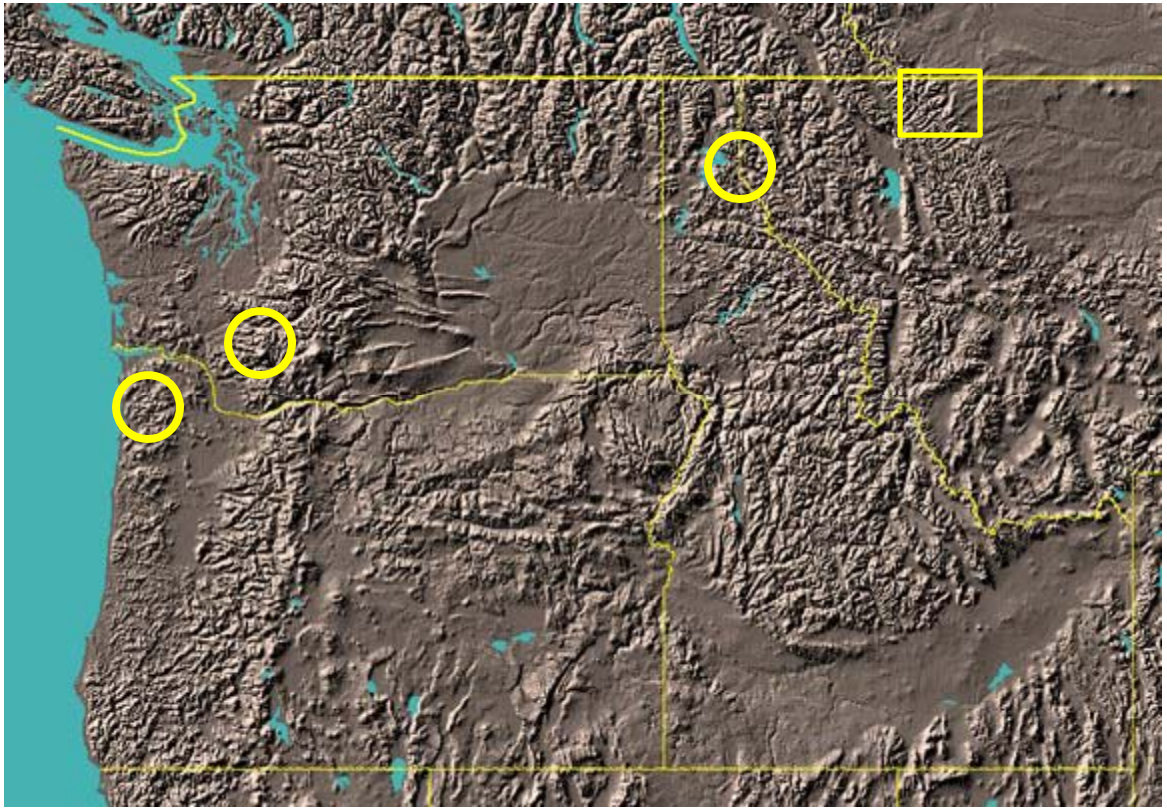
5-7 Nov 2006


B
A
11/06/2006 2127z CloudSat Orbit on AMSR-E TPW (Pac Region)
0
10
20
30
40
50
60
70
75
TPW (mm)

November 6-7, 2006. One storm, three state daily precipitation records !!!

Never in U.S. history have two state records been set on the same day.

Preliminary State-Record Maximum 24-Hour Precipitation		
New Record:	June Lake, Washington, elevation 3,340 feet	15.20 inches on November 6-7, 2006
Former Record:	Mt. Mitchell, Washington, elevation 3,600 feet	14.26 inches on November 23-24, 1986
New Record:	Lee's Camp, Oregon, elevation 660 feet	14.30 inches on November 6-7, 2006
Former Record:	Port Orford, Oregon, elevation 150 feet	11.65 inches on November 19, 1996
New Record:	Bear Mountain, Idaho, elevation 5,400 feet	9.40 inches on November 6-7, 2006
Former Record:	Rattlesnake Creek, Idaho, elevation 4,000 feet	7.17 inches on November 23, 1909



Old records broken by

23 % - Oregon

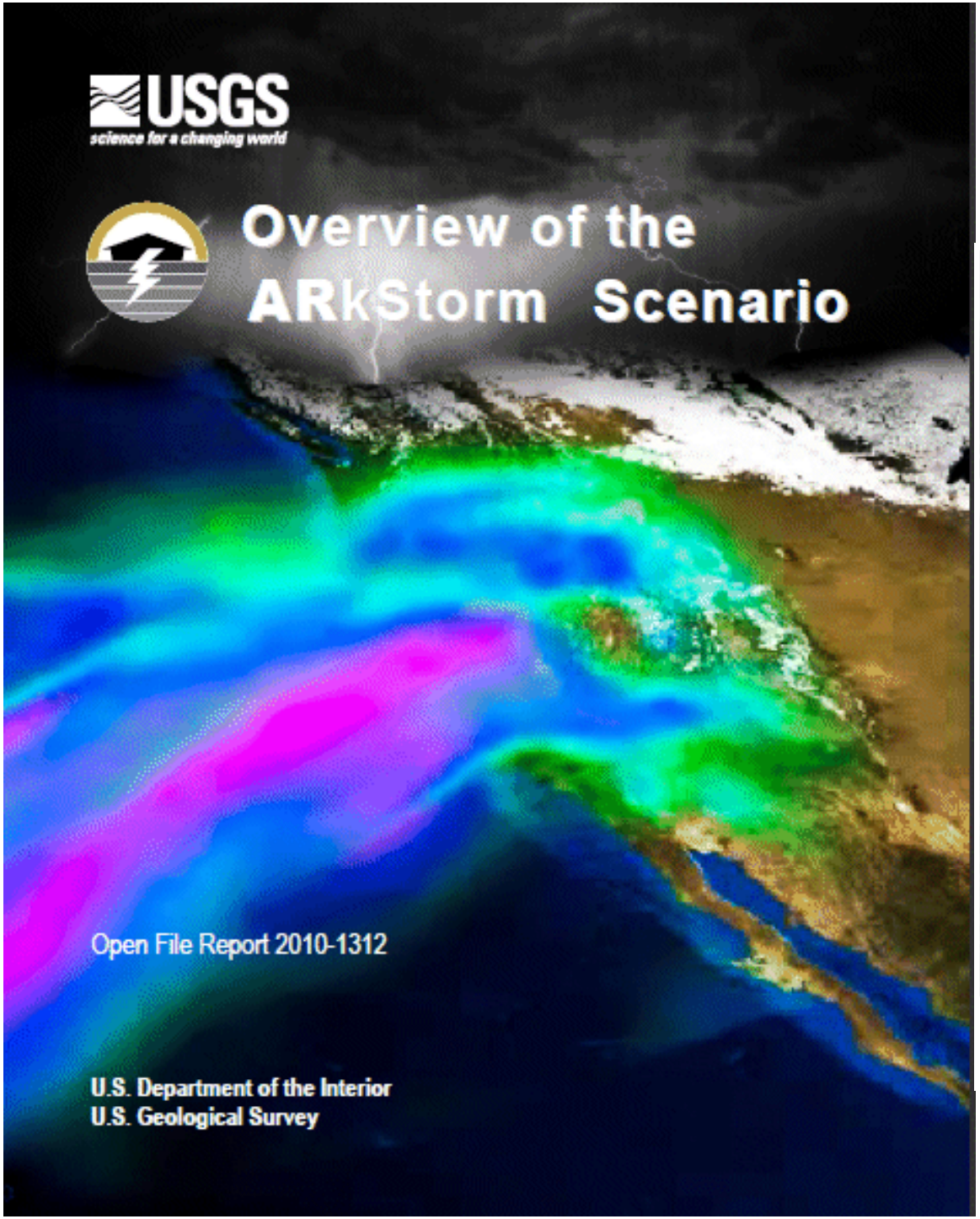
06 % - Washington

31 % - Idaho

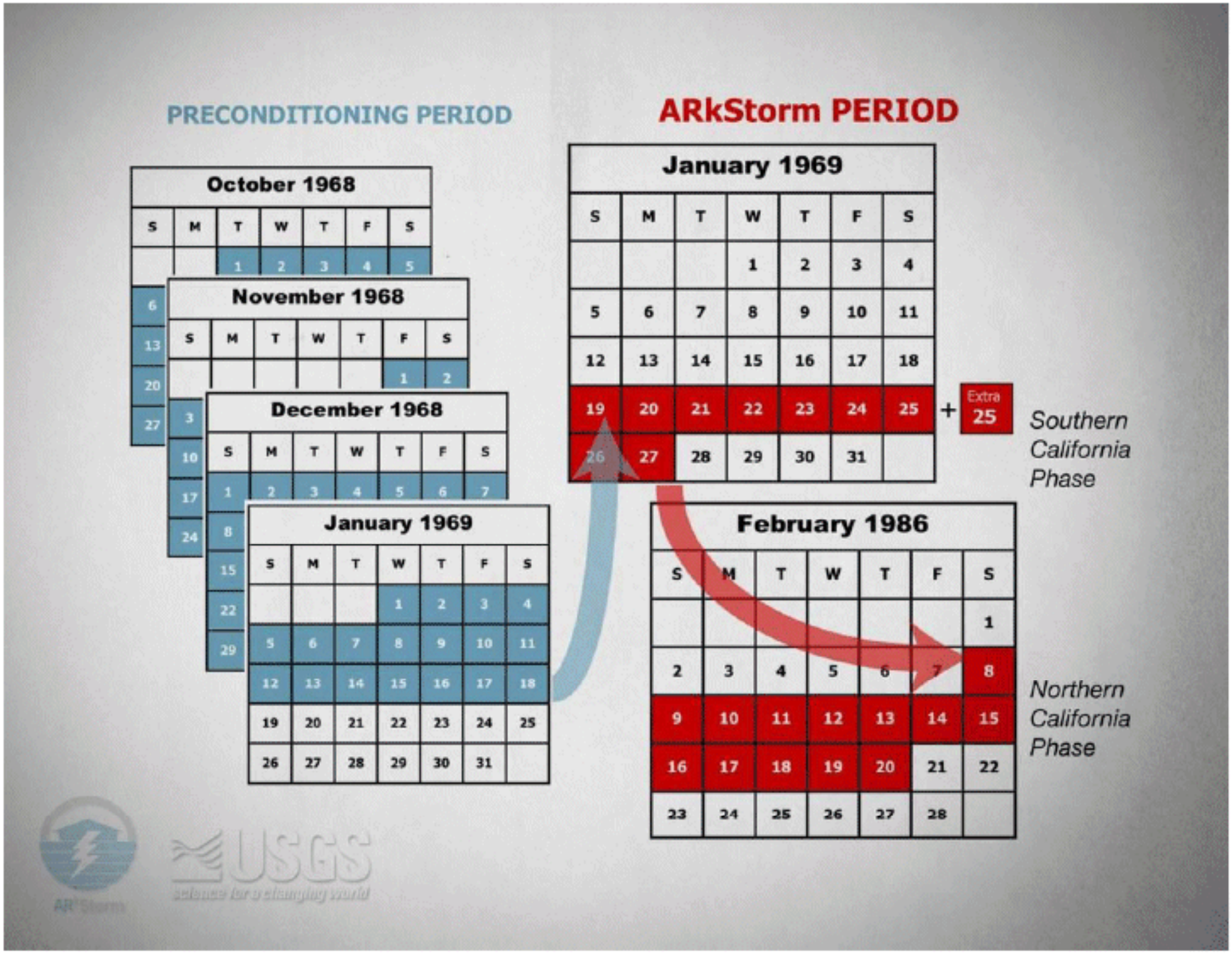
Square:

Many Glacier Lodge

Many Glacier, Nov 2006. NPS.



K Street, Sacramento, looking east
1861-1862


PRECONDITIONING PERIOD
ARkStorm PERIOD
October 1968
November 1968
December 1968
January 1969
January 1969
February 1986
Extra 25
Southern California Phase
Northern California Phase
USGS
science for a changing world
AR²Storm

Select: Lake Tahoe area, 12 months ending in Dec, Temperature 0 C, 9-year running mean.

North American Freezing Level Tracker

About

Introduction

This analysis tool allows one to track through time the height of the freezing level (0 C or 32 F) above sea level. Freezing level has important effects on hydrology in mountain environments. This level affects 1) the elevation of the rain/snow line, 2) whether precipitation at a specified level falls as rain or as snow, 3) whether the ground is frozen or thawed when the first autumn snows fall, 4) the efficiency of snowpack accumulation through the winter months, 4) the internal temperature and rate of "ripening" and melting of the snowpack in the spring, and 6) the length of the snow free season at different elevations. Freezing level also affects ecological function through biological growth rates (both plants and animals) at different elevations. Other temperature thresholds of interest are available (10 C, 20 C, 30 C / 50 F, 68 F, 86 F) as well. These temperatures can be substituted for the term "freezing level" below.

Definition

In the upper atmosphere temperatures are always below freezing everywhere on earth. Starting from the upper atmosphere and working down, the freezing level is taken to be the elevation above sea level in the free atmosphere at which a temperature of 0 C (or 32 F) is first encountered. The mean daily temperature profile used for this process is formed from the four six-hour averages available from Global Reanalysis (see below).

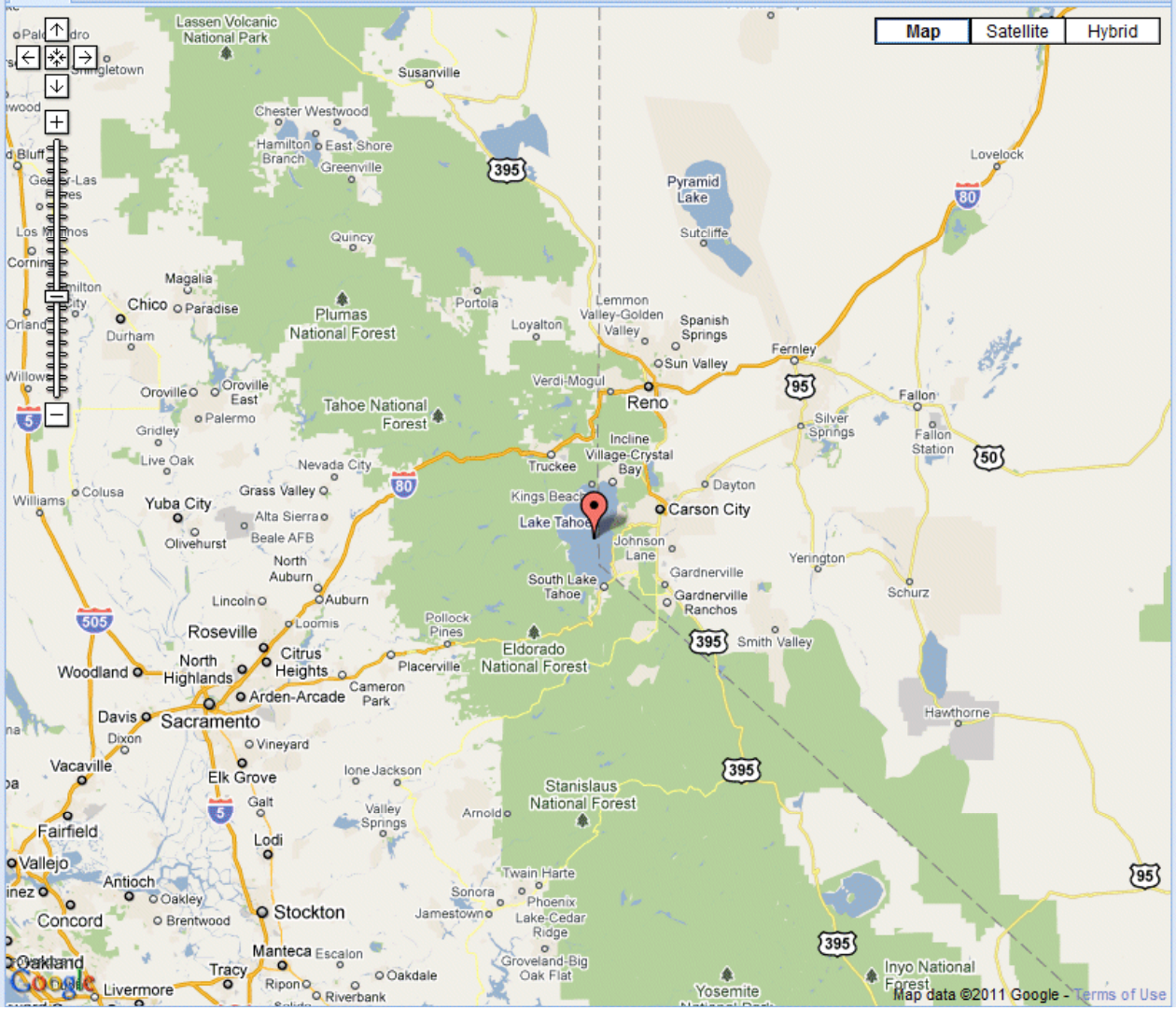
Monthly and seasonal

Contact

Location Selection

Display Options

Map



How to use

Monthly/Seasonal Listings

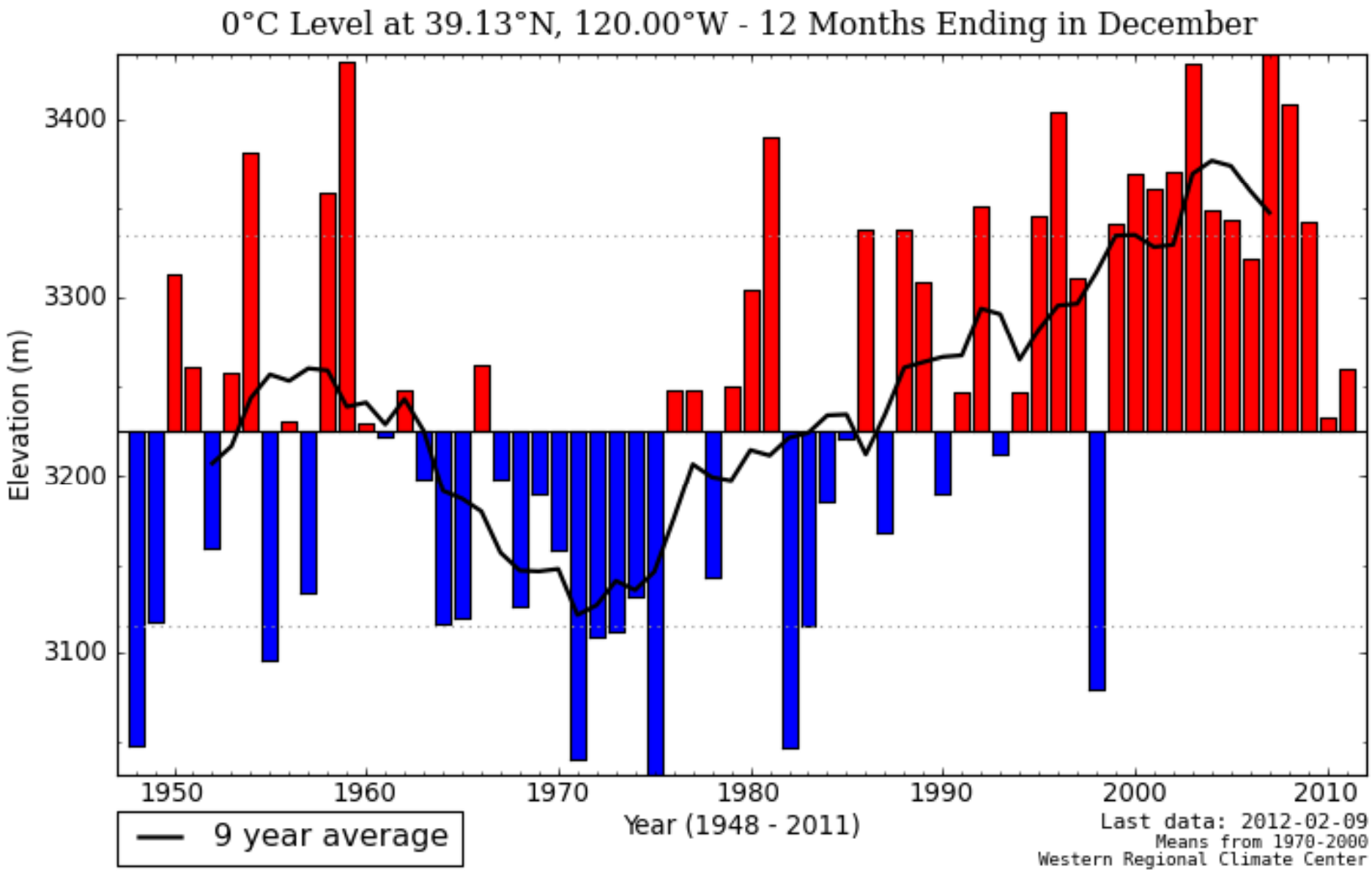
Help

Lat:	39.07464374293251
Lon:	-120.025634765625
Span:	12 Months
End Month:	Dec
Level:	0 C
Running average:	9 Years

Go

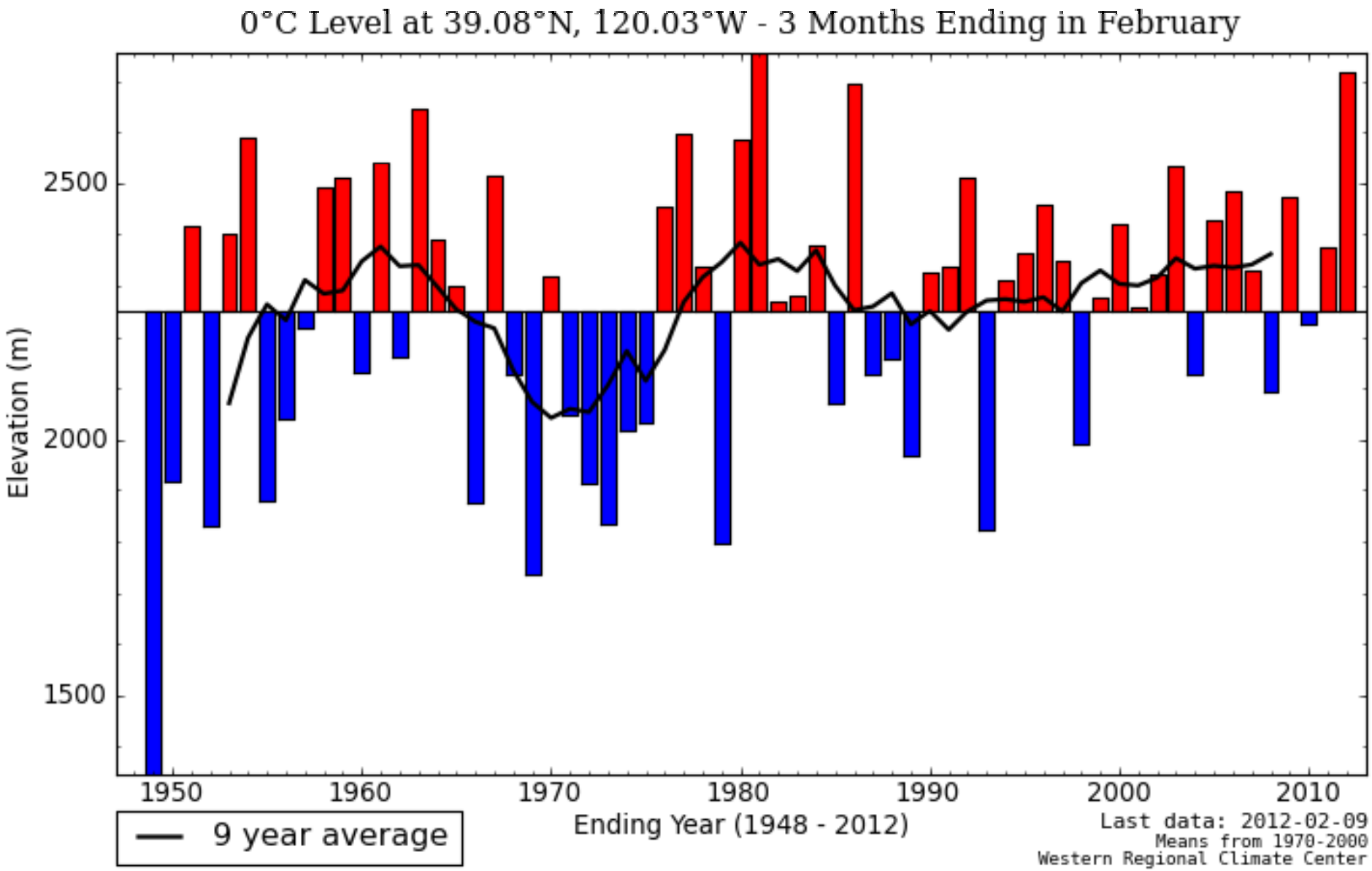
Last 12 Months

Elevation of Freezing Level over Lake Tahoe Annual. 1948 through 2011.

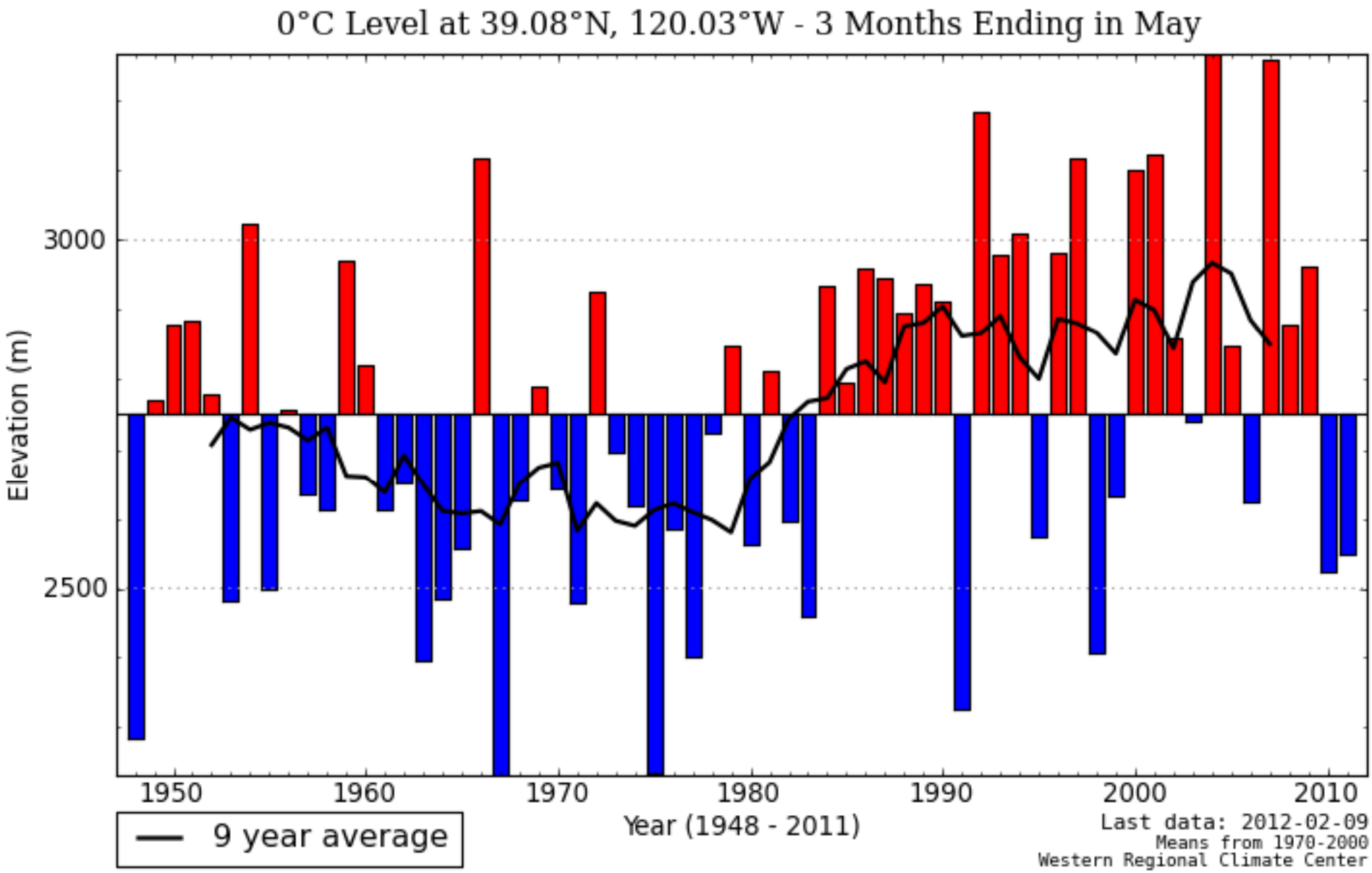


Elevation of Freezing Level over Lake Tahoe. Winter (DJF) 1948 through 2012.

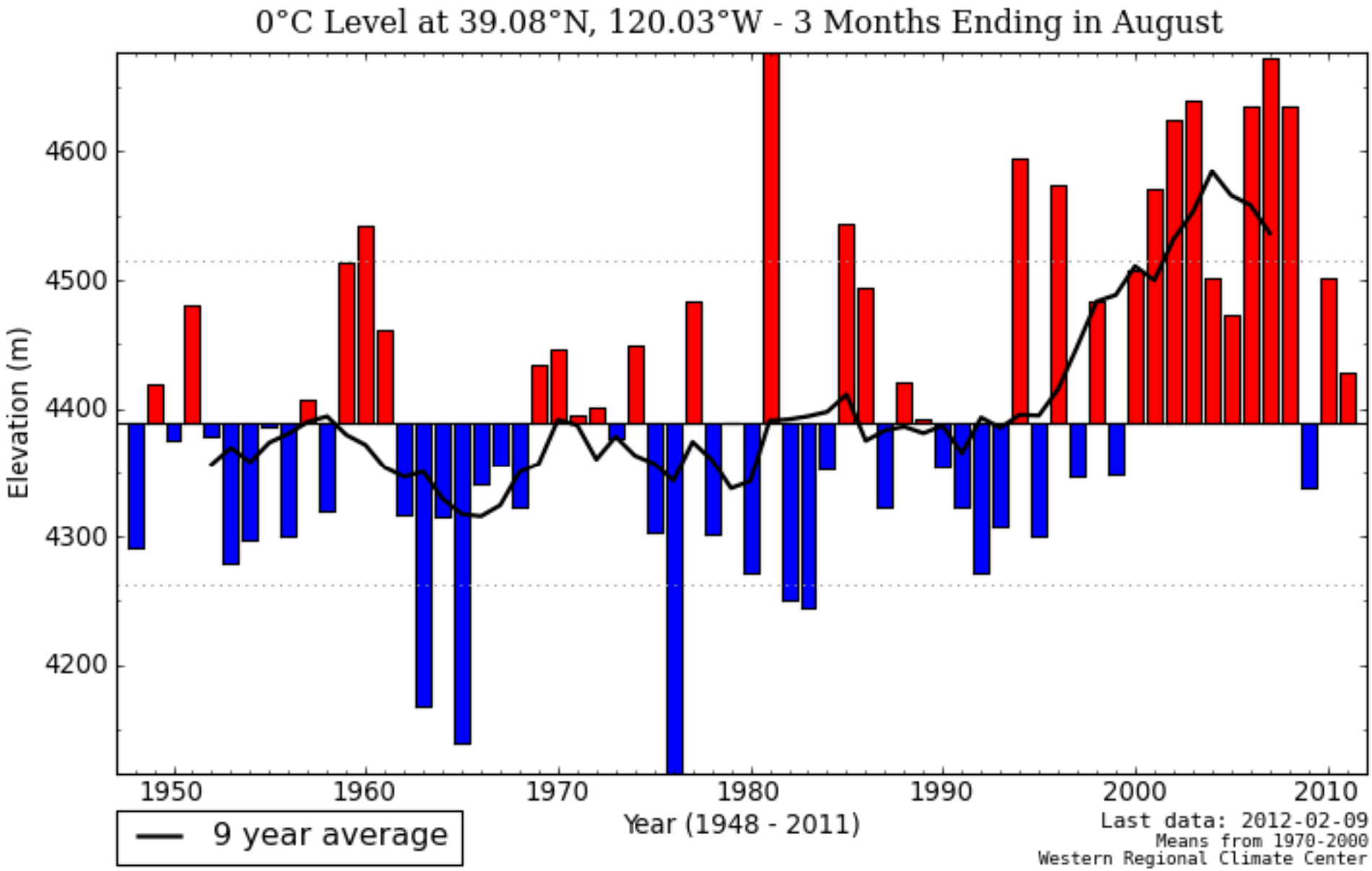
2012 thru Feb 9



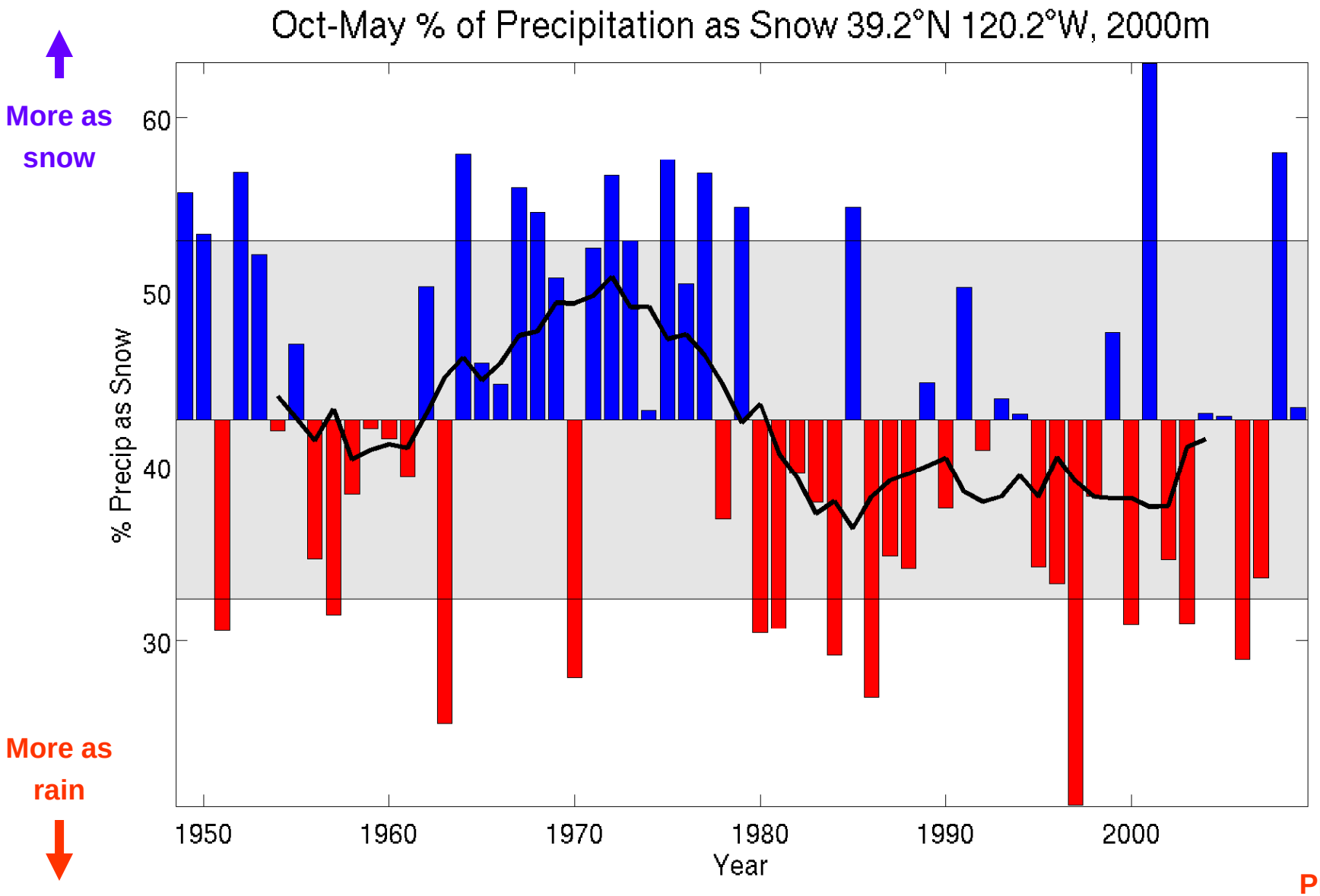
Elevation of Freezing Level over Lake Tahoe. Spring (MAM). 1948 through 2011.



Elevation of Freezing Level over Lake Tahoe. Summer (JJA). 1948 through 2011.

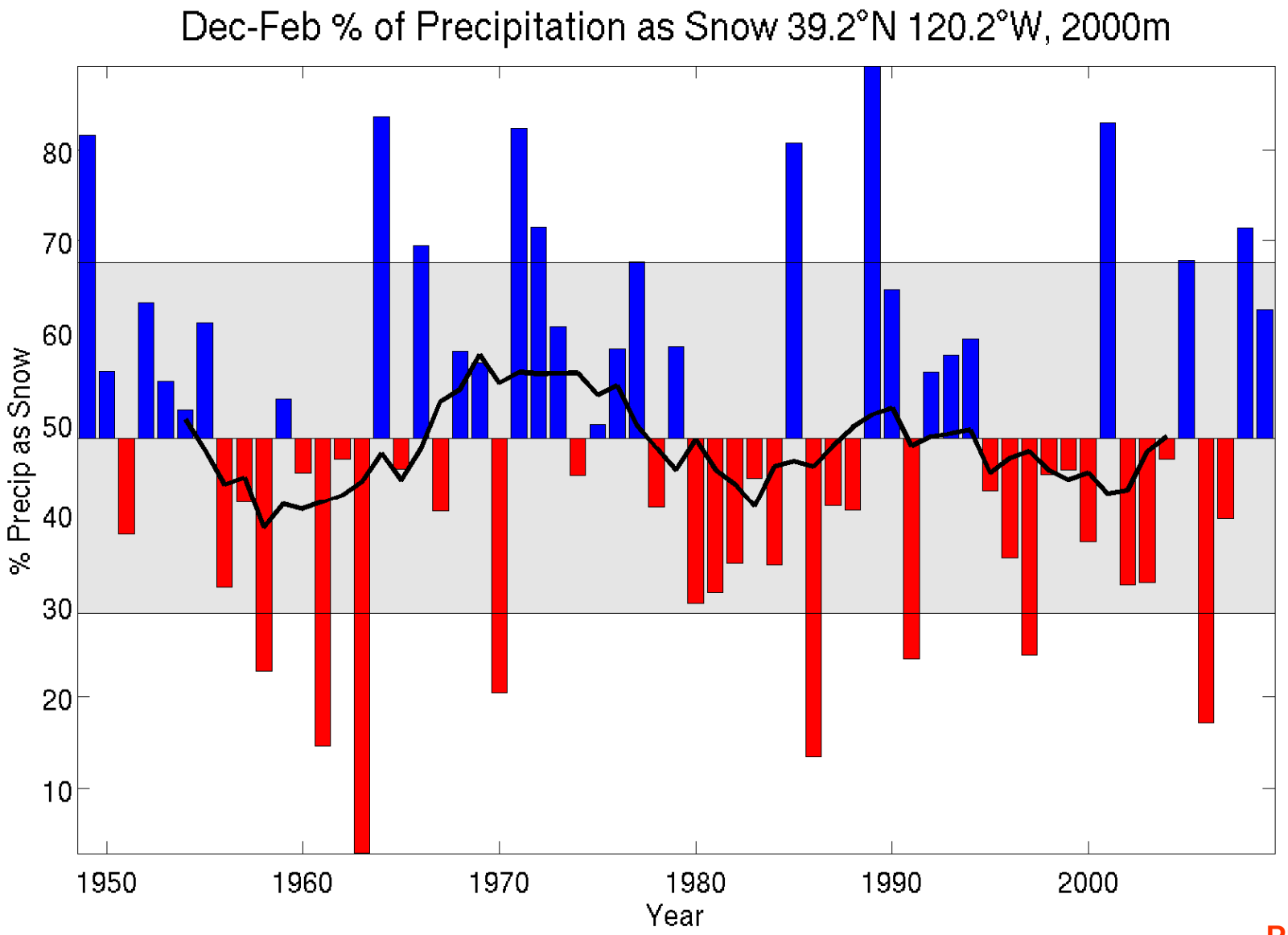


Percent of Cool Season Precipitation Falling with Freezing Level Below 2000 m (6562 ft).
Larger fraction implies more precipitation as snow, less as rain.
Lake Tahoe. 1948-2009. NCEP Reanalysis Precipitation and Temperature.



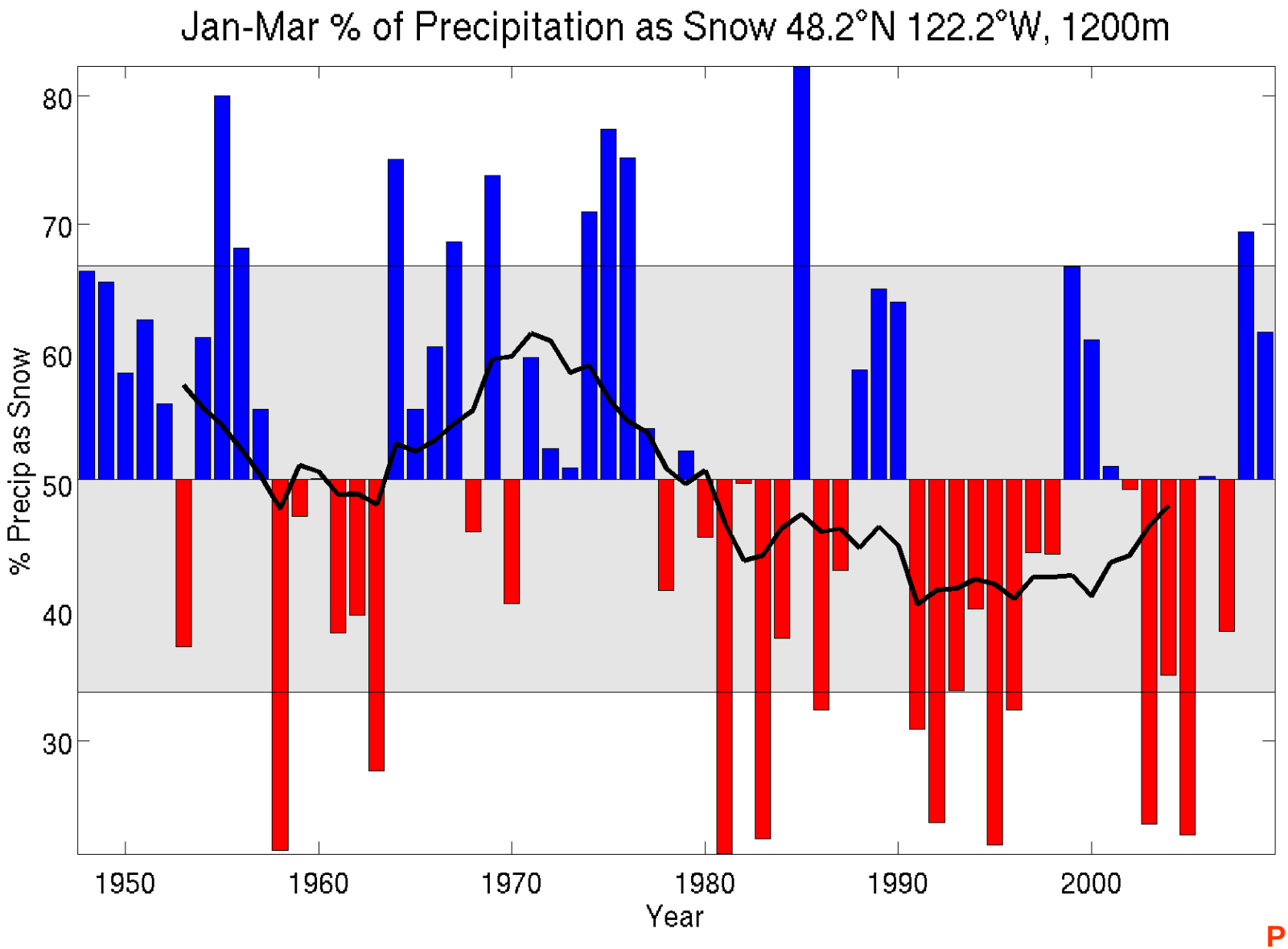
Prototype
John Abatzoglou

Percent of Winter Precipitation Falling with Freezing Level Below 2000 m (6562 ft).
Larger fraction implies more precipitation as snow, less as rain.
Lake Tahoe. 1948-2009. NCEP Reanalysis Precipitation and Temperature.



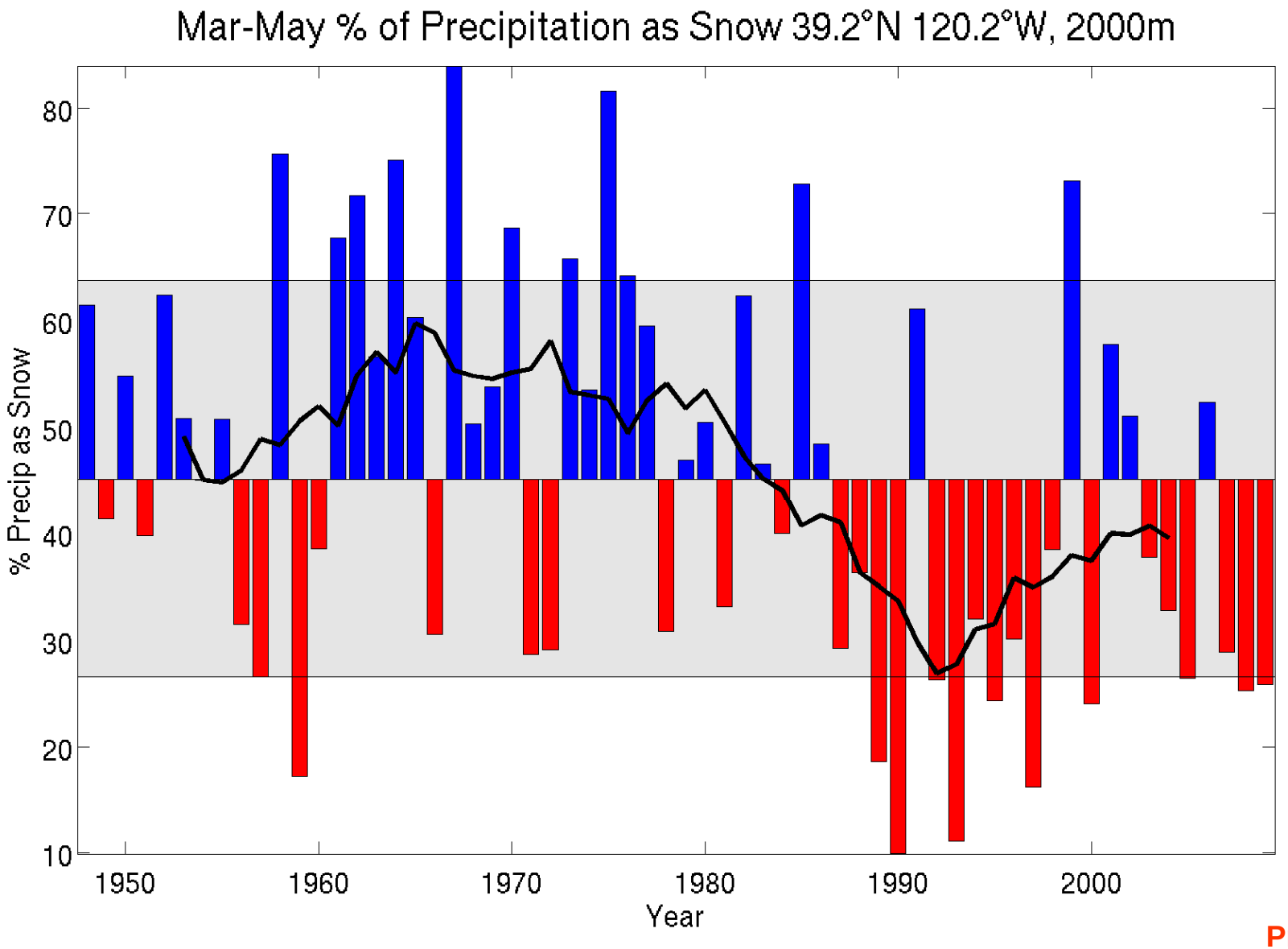
Prototype
John Abatzoglou

Percent of Jan-Mar Precipitation Falling with Freezing Level Below 2000 m (6562 ft).
Larger fraction implies more precipitation as snow, less as rain.
Lake Tahoe. 1948-2009. NCEP Reanalysis Precipitation and Temperature.



Prototype
John Abatzoglou

Percent of Spring Precipitation Falling with Freezing Level Below 2000 m (6562 ft).
Larger fraction implies more precipitation as snow, less as rain.
Lake Tahoe. 1948-2009. NCEP Reanalysis Precipitation and Temperature.



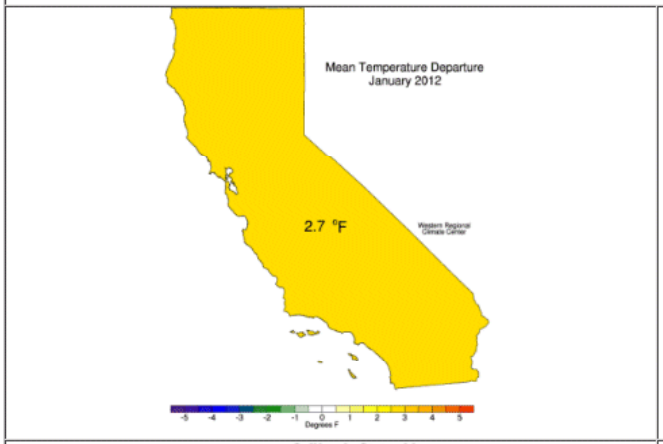
Prototype
John Abatzoglou

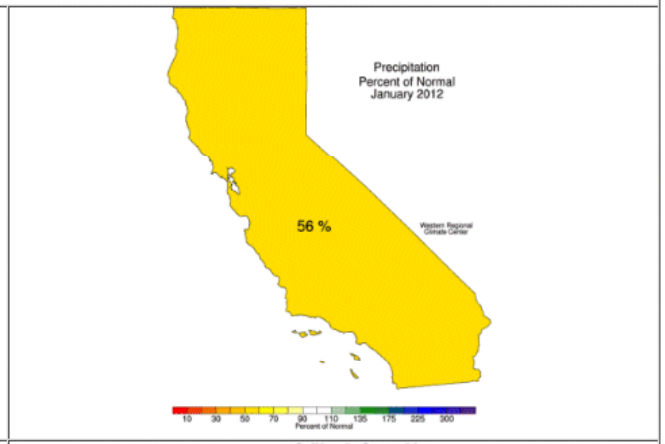
California Climate Tracker

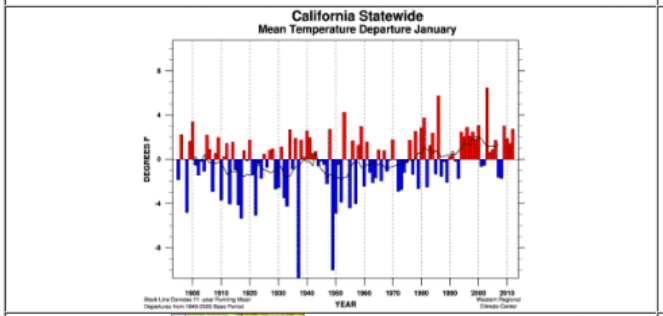
Tracking Climate Variability and Change for the State

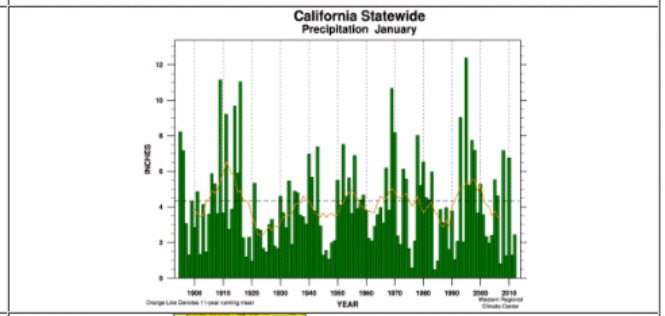
Explore Climate Products

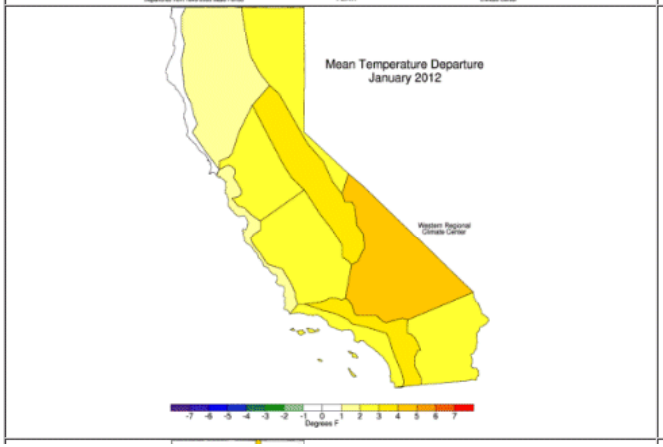
JANUARY 2012

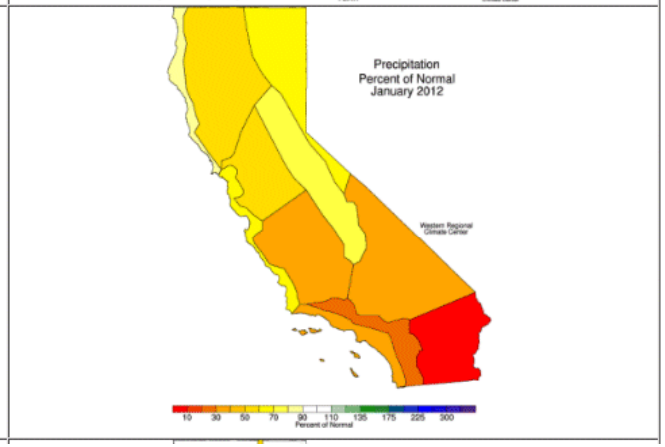










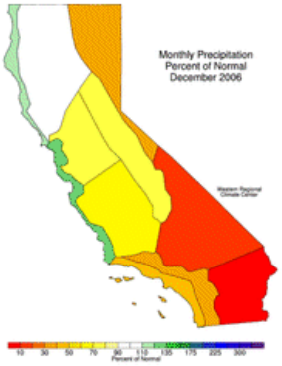


Updated Monthly by John Abatzoglou

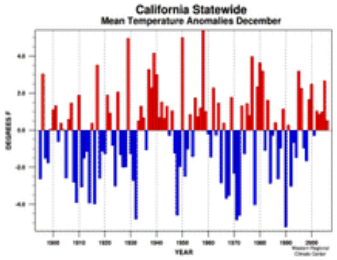
California Climate Tracker

Select from the Menu to the Right

Latest Graphics



Time Series



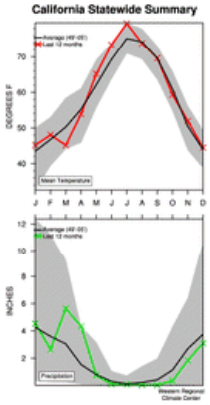
Latest Graphics

Select Region
Select Element
Select Data Type
Select Time Period
Select

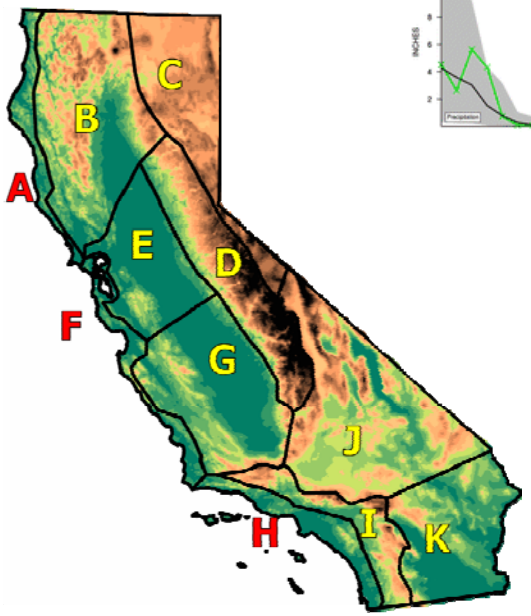
Time Series

Select Region
Select Element
Select Time Period
Select

Last 12 Months



- Climate region data: 1895 to present
- Averages taken from: 1949-2005



Time Series

Sierra
Select Region
Statewide
Sierra
Northeast
North Central
Sacramento-Delta
San Joaquin Valley
North Coast
Central Coast
South Coast
South Interior
Mohave
Sonoran

Time Series

Select Region
Select Element
Select Element
Maximum Temperature
Minimum Temperature
Mean Temperature
Precipitation
Temperature Summary

Time Series

Select Region
Select Element
Select Time Period
March
April
May
June
July
August
September
October
November
December
Winter (DJF)
Spring (MAM)
Summer (JJA)
Autumn (SON)
Calendar Year (Jan-Dec)
Water Year (Oct-Sep)
Water Year (Jul-Jun)
January to Present
October To Present
July To Present

Summary of the Past 12 Months

Select Region GO

Climate Regions
Plot Data

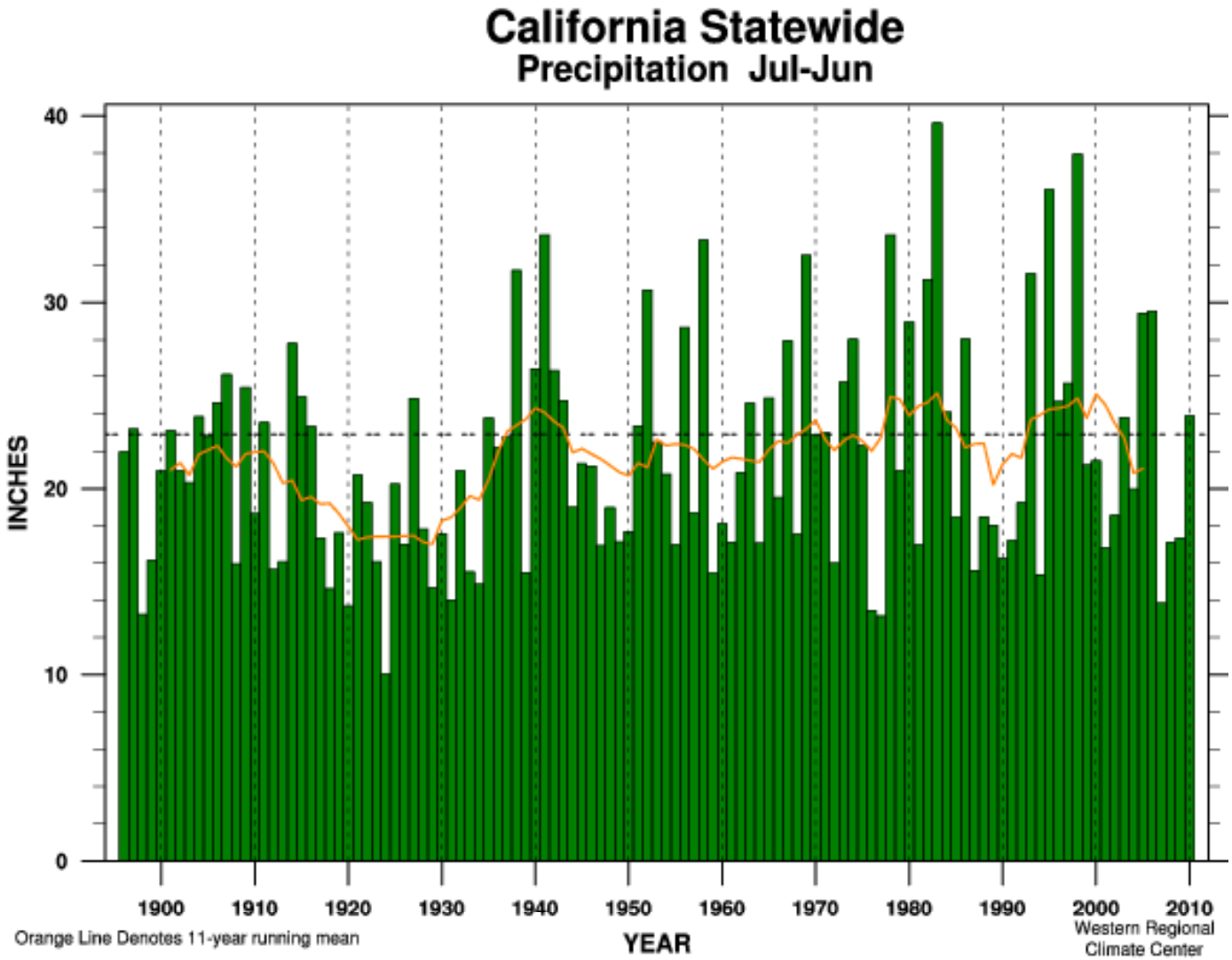
More Info
Retrieve Data

Back to the California Climate Tracker
Non-Frames Version

Western Regional Climate Center
DRI Desert Research Institute
Powered by ACIS NOAA Regional Climate Centers

Several types of summaries and presentations available.

Could add extremes.



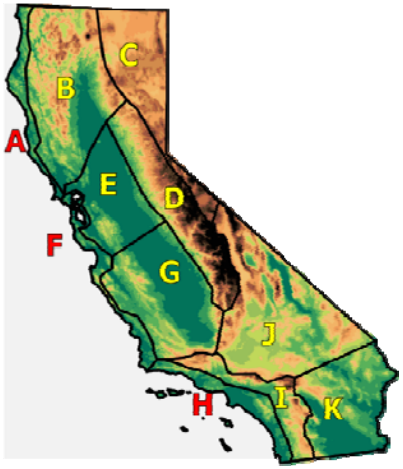
Linear Trend 1895-present	+ 3.27 ± 3.18 in.	(+ 14 ± 13%) per 100 yr		
Linear Trend 1949-present	+ 0.44 ± 9.43 in.	(+ 1 ± 41%) per 100 yr		
Linear Trend 1975-present	- 3.22 ± 25.08 in.	(- 14 ± 109%) per 100 yr		
Wettest Year	39.63 in. (173%)	in 1983	MEAN	22.89 in.
Driest Year	10.03 in. (43%)	in 1924	STDEV	6.46 in.
Jul-Jun 2010	23.89 in. (104%)		RANK	82 of 115

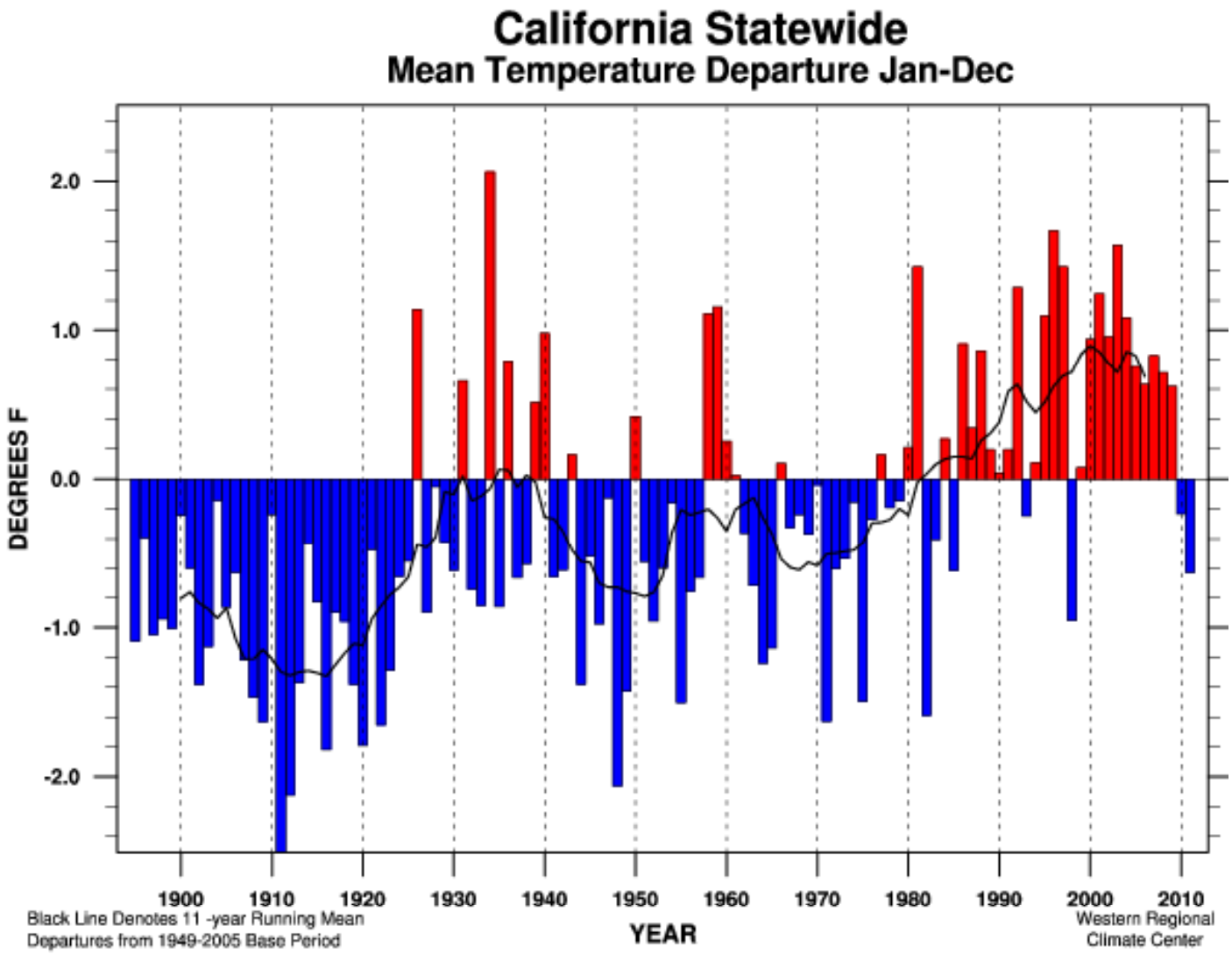
Winter-Centered July-June Precipitation

California Statewide

1895/96 - 2010/11

Develop an "Extremes" Analog





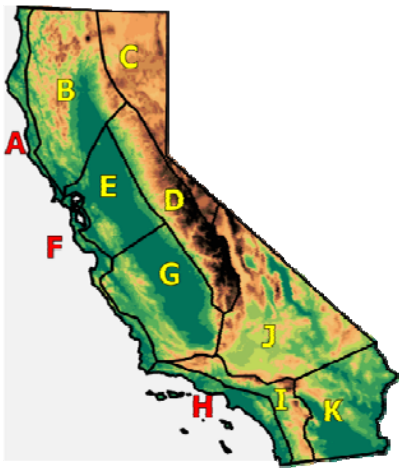
Linear Trend 1895-present		+ 1.47 ± 0.42 °F/100yr		
Linear Trend 1949-present		+ 2.33 ± 1.02 °F/100yr		
Linear Trend 1975-present		+ 2.80 ± 2.37 °F/100yr		
Warmest Year		58.1°F (+ 2.1°F) in 1934	MEAN	56.1°F
Coldest Year		53.6 °F (- 2.5 °F) in 1911	STDEV	0.87 °F
Jan-Dec	2011	55.4 °F (- 0.6 °F)	RANK	44 of 117

Annual Calendar Year Temperature Departure

California Statewide

1895 - 2011

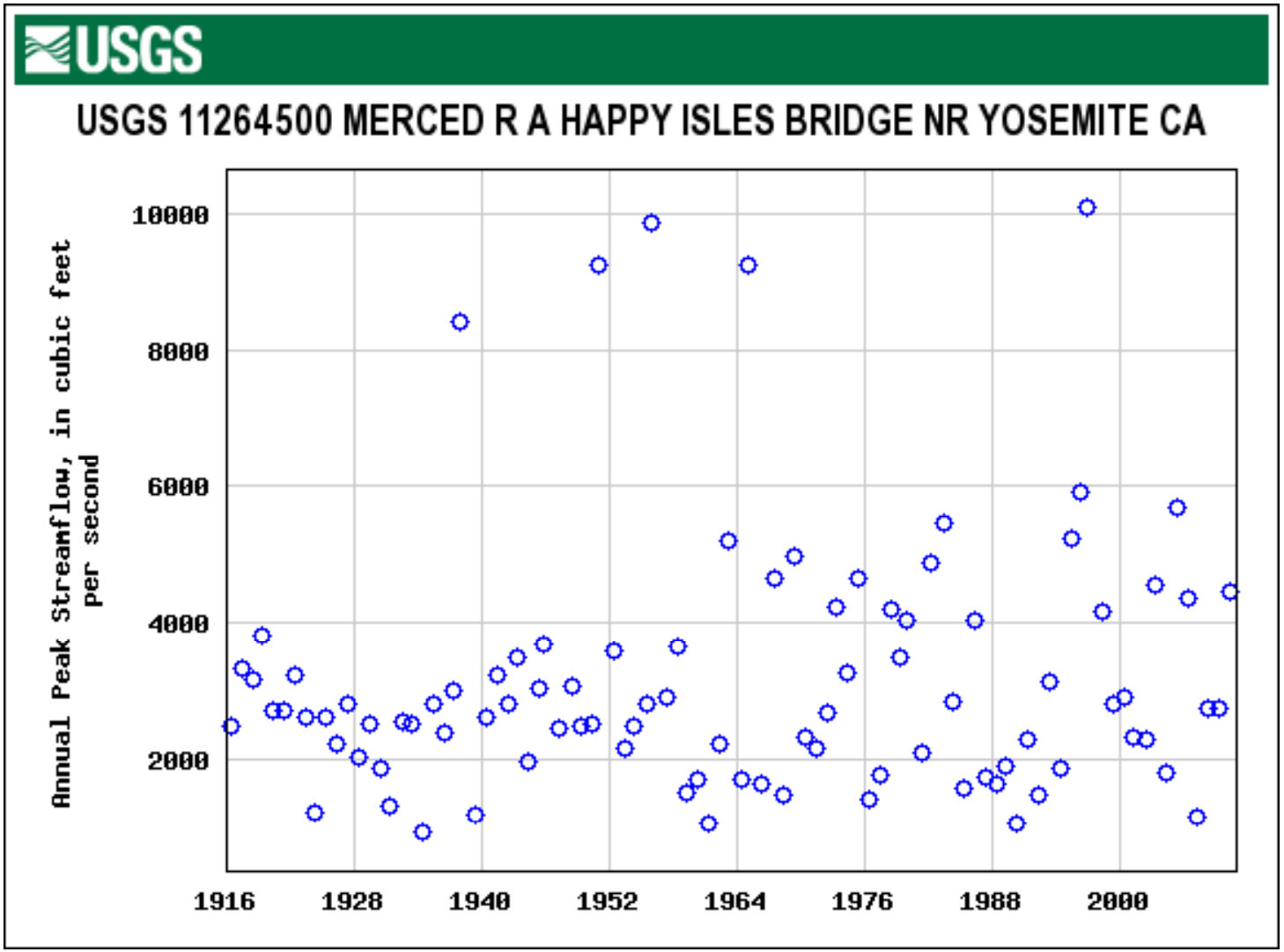
Develop an "Extremes" Analog



USGS NWIS. Annual Peak Discharge. Happy Isles, Yosemite.

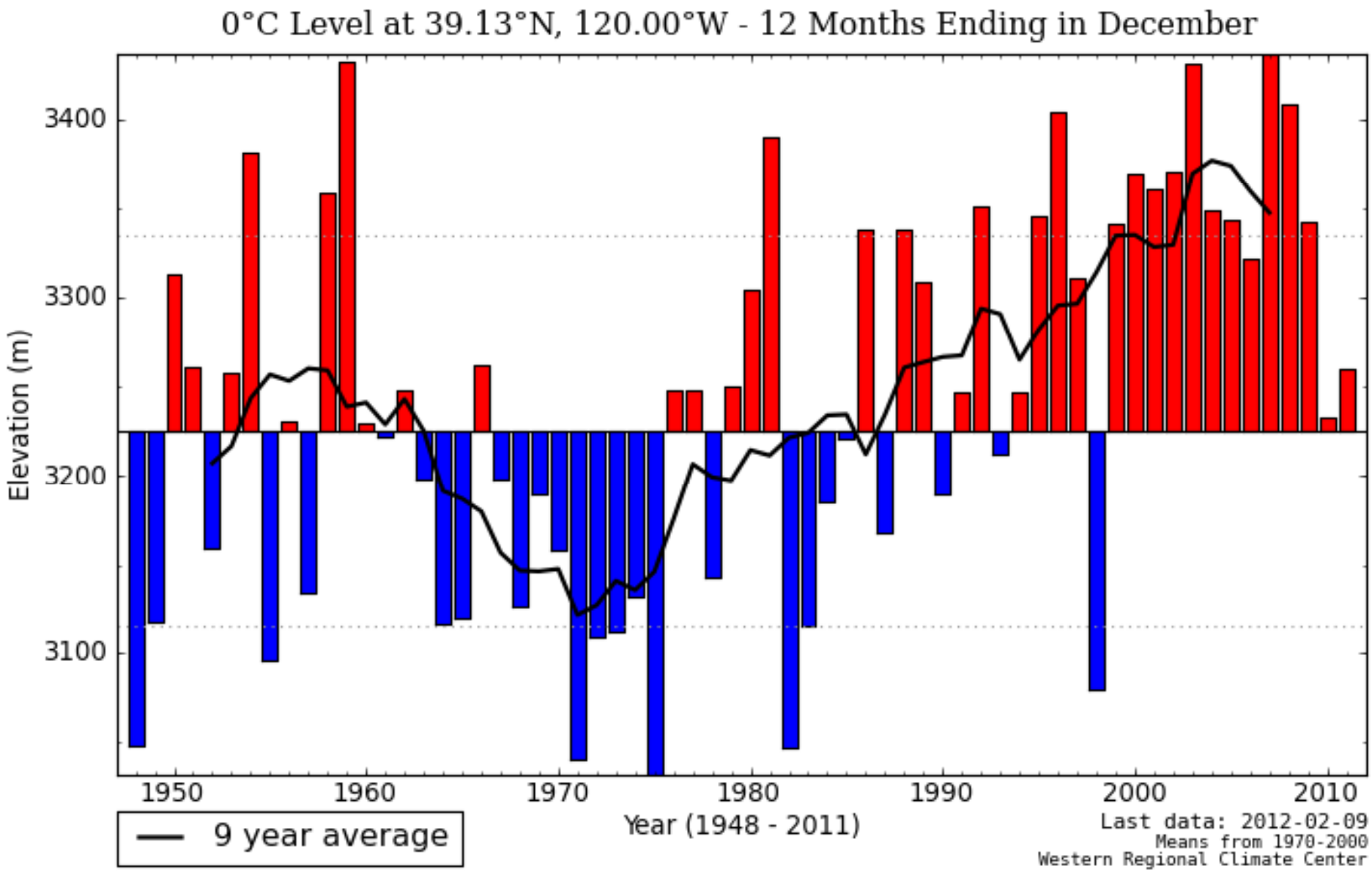
Need a climate analog of this capability for NOAA and other stations.

A good NOAA or joint NOAA-DOI application for ACIS.



Elevation of Freezing Level over Lake Tahoe Annual. 1948 through 2011.

Currently updated daily. Develop an "Extremes" version.



Desirable Characteristics of Observation Systems for Non-stationarity Research

- This topic places the greatest demands on observational data sets

- Records that are as long as possible (many decades or more)
- Records that are as complete as possible (few or no missing observations)
- Safeguards to ensure that the most extreme values are accurately observed
  - Equipment, procedures to capture the "worst of the worst" conditions
  - Extremes often place the greatest physical test on observing systems
    - Annual or partial duration series are single values among thousands
- Consistency through time of climate records
  - Consistency in sensing equipment when possible
  - Consistency in observational procedures and reporting practices
  - Consistency in site exposure
- Systematic documentation of all factors that can produce non-stationarity
- High standards for quality control
  - Extreme readings are most likely to trigger flags of "suspect"
  - Extreme readings are most likely to be rejected
  - Just one value out of thousands, QC systems may not treat as "special"
  - Often are identified retrospectively, rather than in real time
- Operational tools to access and visualize records of extremes
  - Promotes strong feedback loops with operations / maintenance
  - California Climate Tracker approach (also Jim Goodridge - style updates)
- Lengthy and sustained commitment is completely necessary

Concluding Comments

- General expectation that some precipitation extremes may increase somewhat
- (Yes, the weasel words are deliberate)
- Not a lot of confidence in dynamical component (convergence mechanisms)
- More confidence in moisture content component (favors shorter events)
- Clausius-Clapeyron is well-established fact

- Not clear whether Atmospheric Rivers would change much in frequency
- They will still happen.

- Plausible: The most extreme Atmospheric Rivers have greater vapor content

- More plausible yet:
- Snow levels will go up
- Snow will still occur, even at lower elevations (just less often)
- More rain, more often, at higher elevations
- Potential for rain-on-snow floods goes up

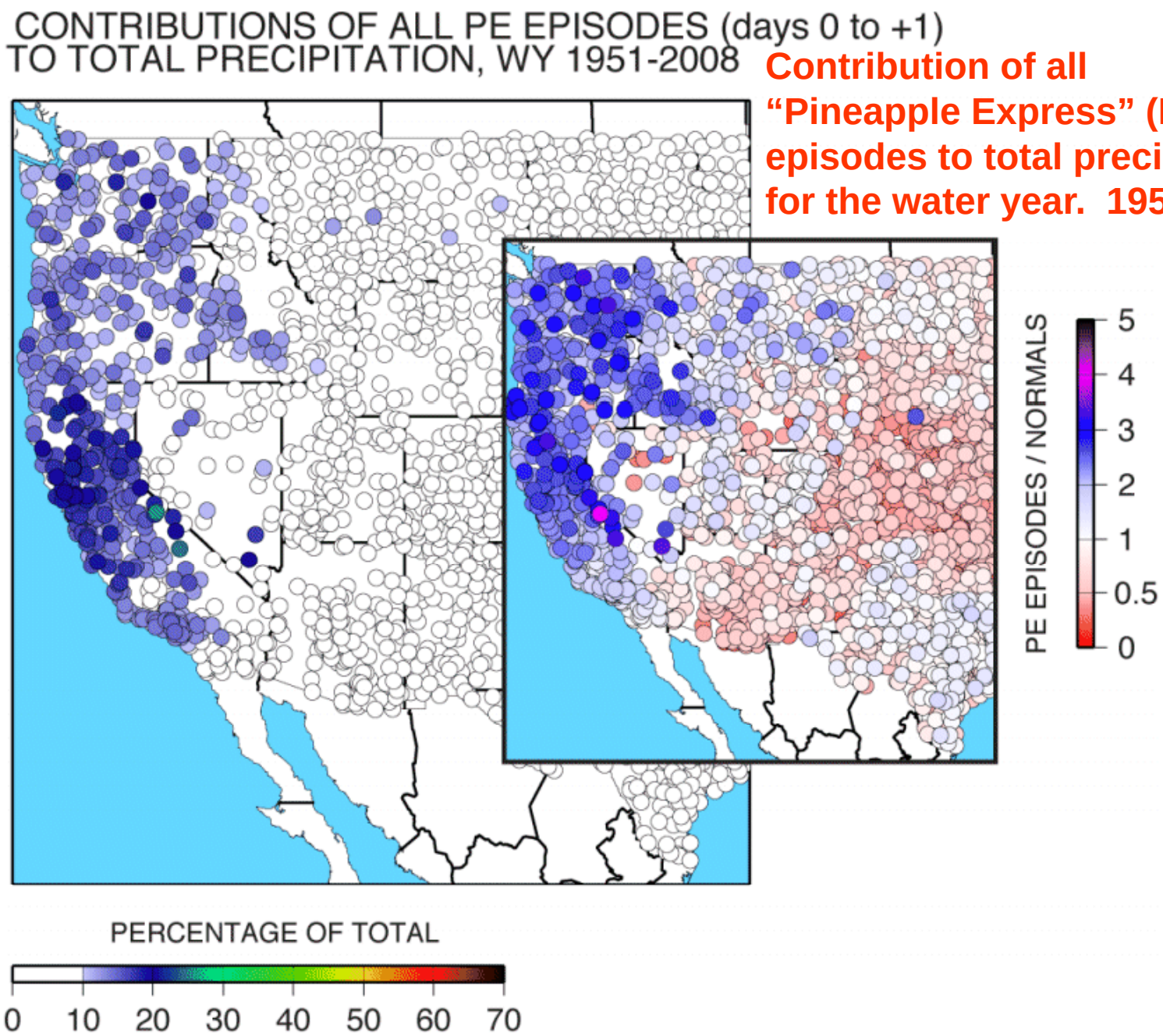
- Flood potential could go up more because of rain/snow than moisture content

- Still possible that both flood and drought frequency go up
- More rain-on-snow, more rain higher up, in mid-winter - floods
- Lack of big events could mean insufficient seasonal precipitation - droughts

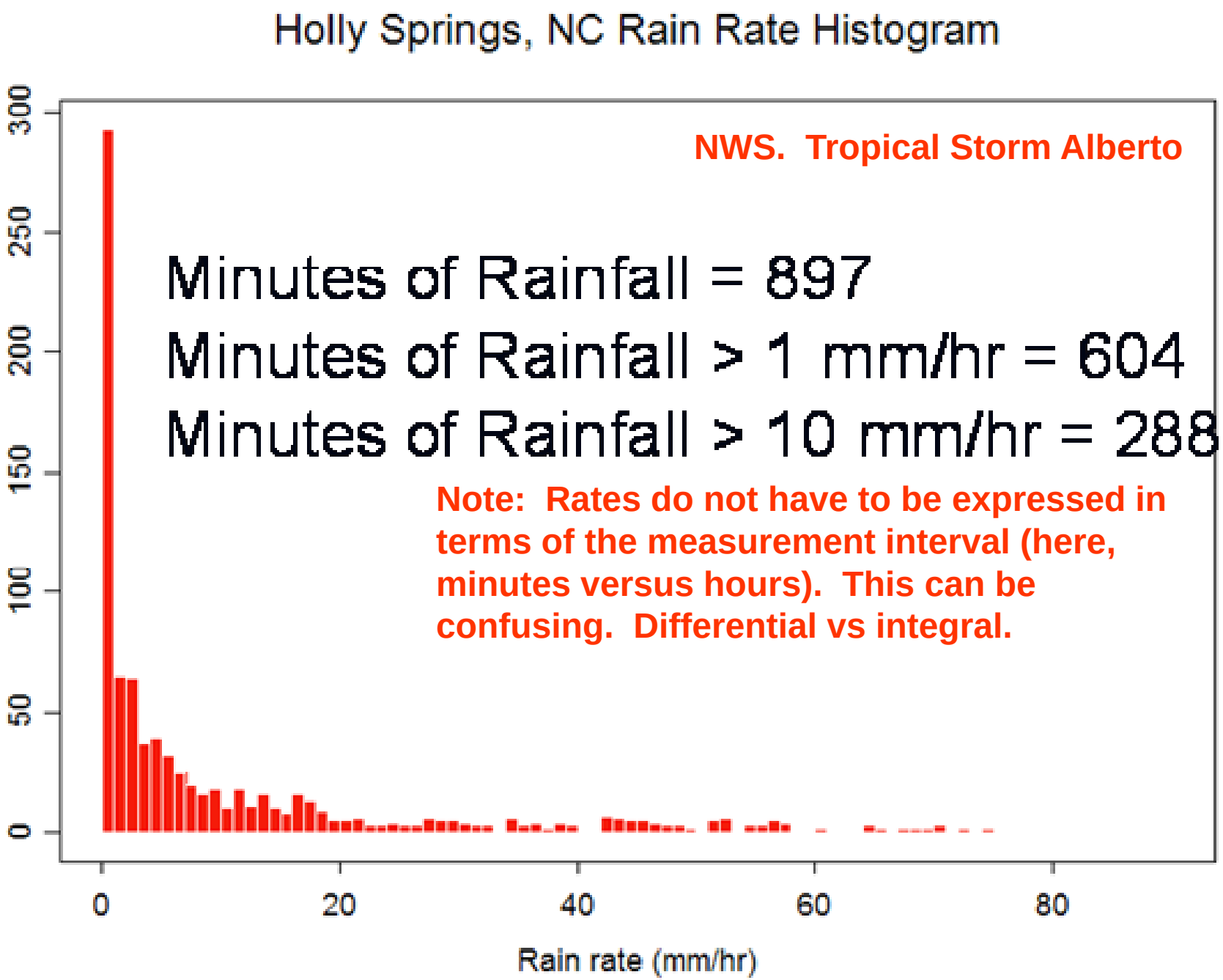
YOUNG
Thank
You !
20101008

DISCARDS

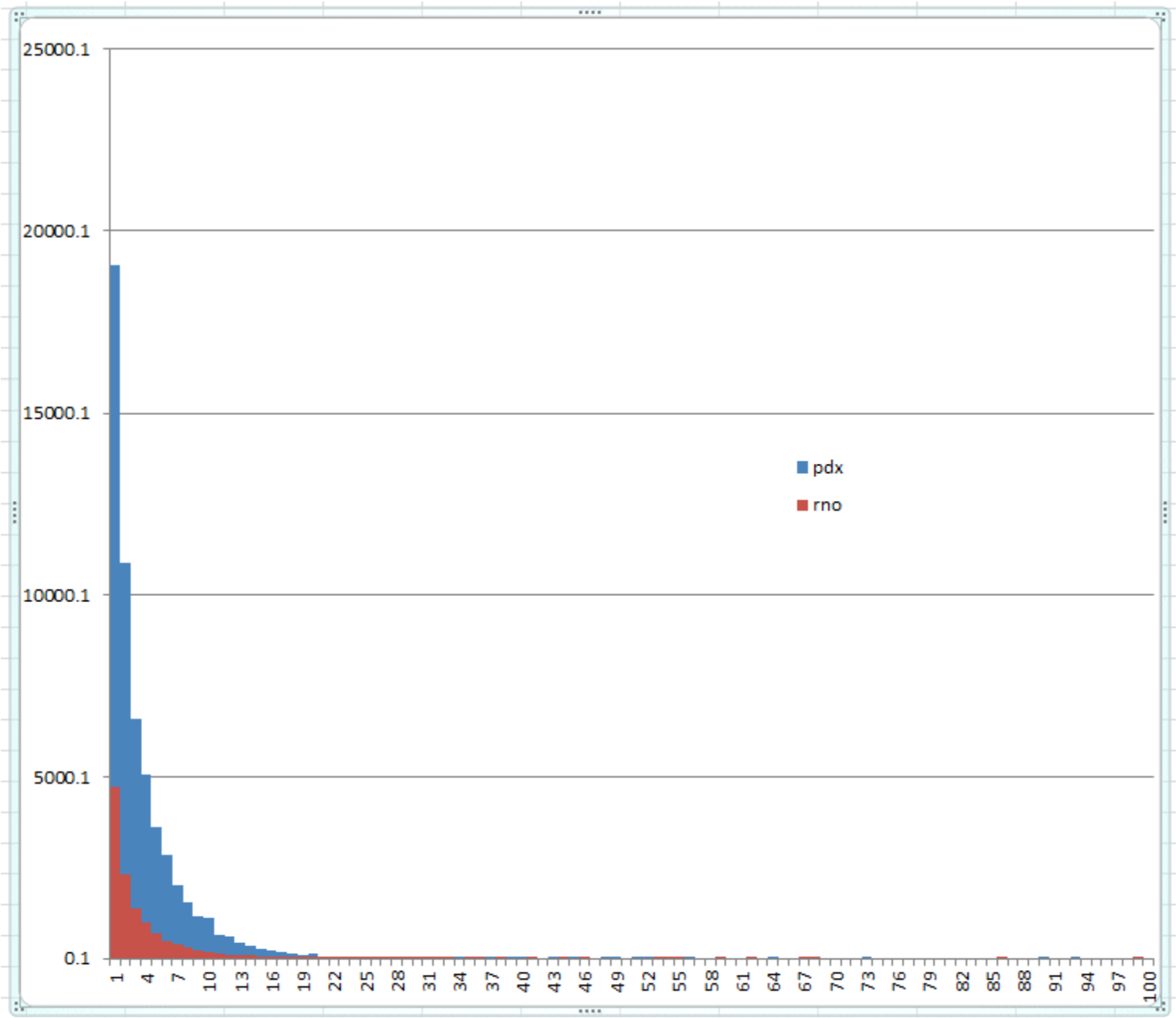
Figure 7. Same as Figure 6, except for PE days from water year 1951–2008, based on Table 2.



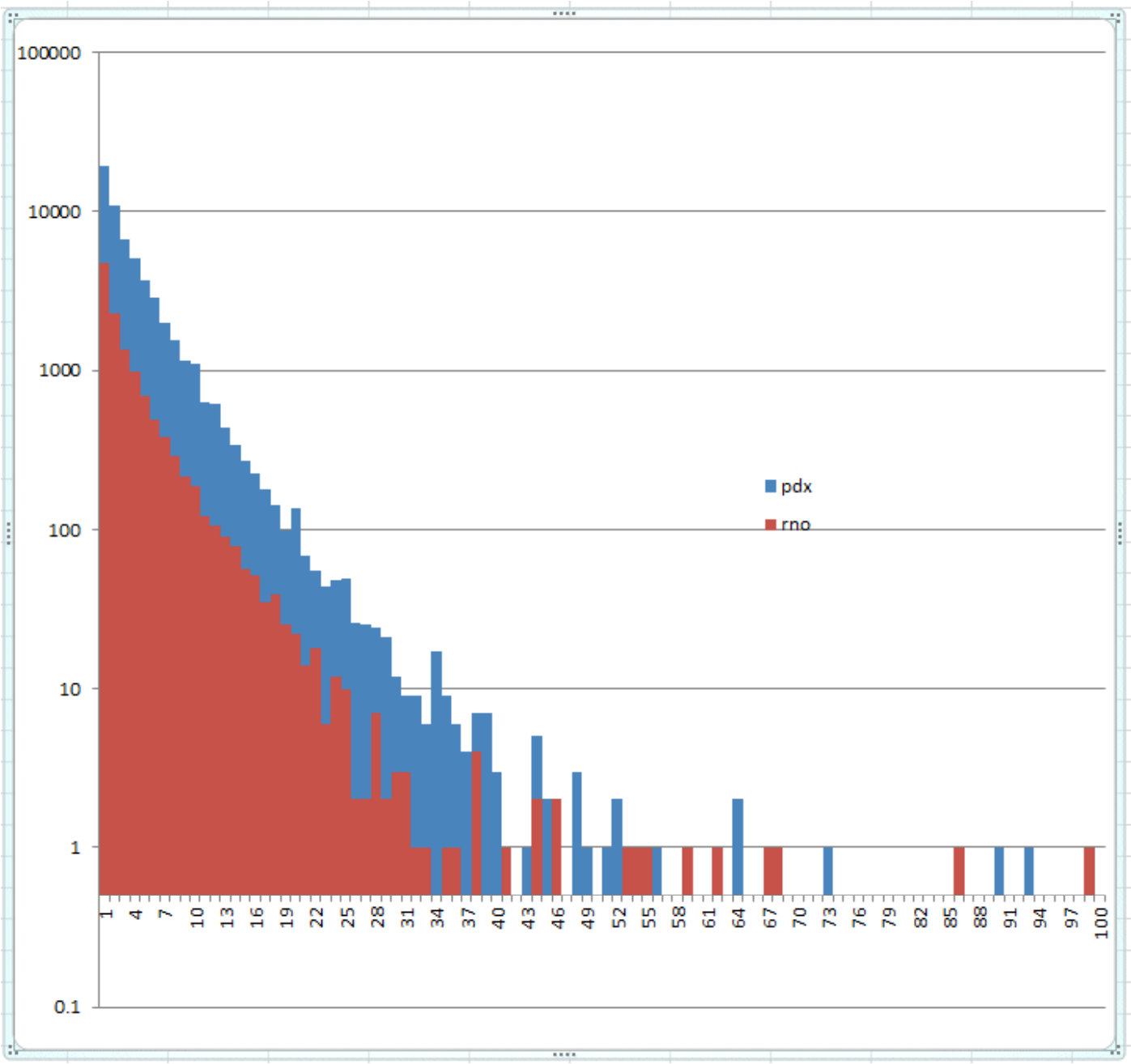
Contribution of all "Pineapple Express" (PE) episodes to total precipitation for the water year. 1951 - 2008.


Holly Springs, NC Rain Rate Histogram
NWS. Tropical Storm Alberto
Minutes of Rainfall = 897
Minutes of Rainfall > 1 mm/hr = 604
Minutes of Rainfall > 10 mm/hr = 288
Note: Rates do not have to be expressed in terms of the measurement interval (here, minutes versus hours). This can be confusing. Differential vs integral.
0
50
100
150
200
250
300
0
20
40
60
80
Rain rate (mm/hr)

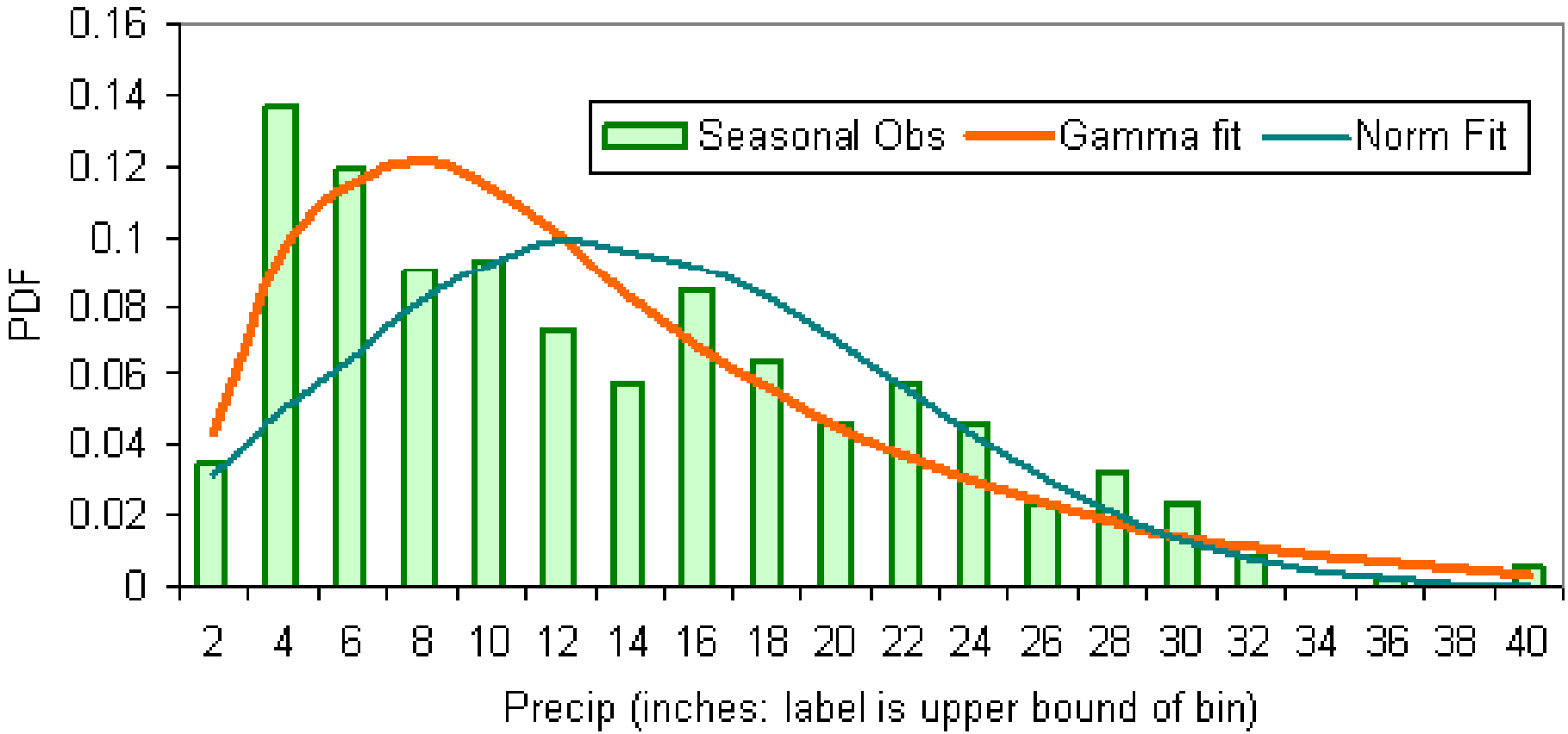
Distribution of hourly precipitation, July 1948-Dec 2008. Reno and Portland. Units: Hundredths of inches. Linear Scale.



Distribution of hourly precipitation, July 1948-Dec 2008. Reno and Portland.
Units: Hundredths of inches. Logarithmic Scale.



Seasonal Precipitation. Olympia Airport, WA.
Mean: 12.5”. St Dev: 8.2” Shape Parameter: 1.97 Scale Parameter: 6.35



NWS PCU 2