RECLAMATION

Managing Water in the West

Drought Reoccurrence Analysis for the Stanislaus River Basin

Levi Brekke, D-8520

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U.S. Department of the Interior
Bureau of Reclamation

Outline

1. Questions on Drought Reoccurrence
2. Analysis Methods
3. Repeating Analysis on Different Datasets
4. Results
5. Critical Assumptions of the Analysis
6. Summary

Questions

1. Apparent reoccurrence of 6-year droughts in the Stanislaus River Basin?

2. Change in apparent reoccurrence given records prior to New Melones operation?

3. Change in apparent reoccurrence given precipitation- vs. runoff-defined drought?

Preview

- Drought reoccurrence analysis was conducted for the Stanislaus River Basin region and 6-year droughts.
- Apparent reoccurrence varies with period of observed record, hydrologic variable, and monitoring location.
- Apparent reoccurrence of the 1987-1992 drought based on synthetic modeling appears to exceed “observed” reoccurrence in the hydrologic record. The synthetic and observed reoccurrence of the 1929-1934 appear to be similar.

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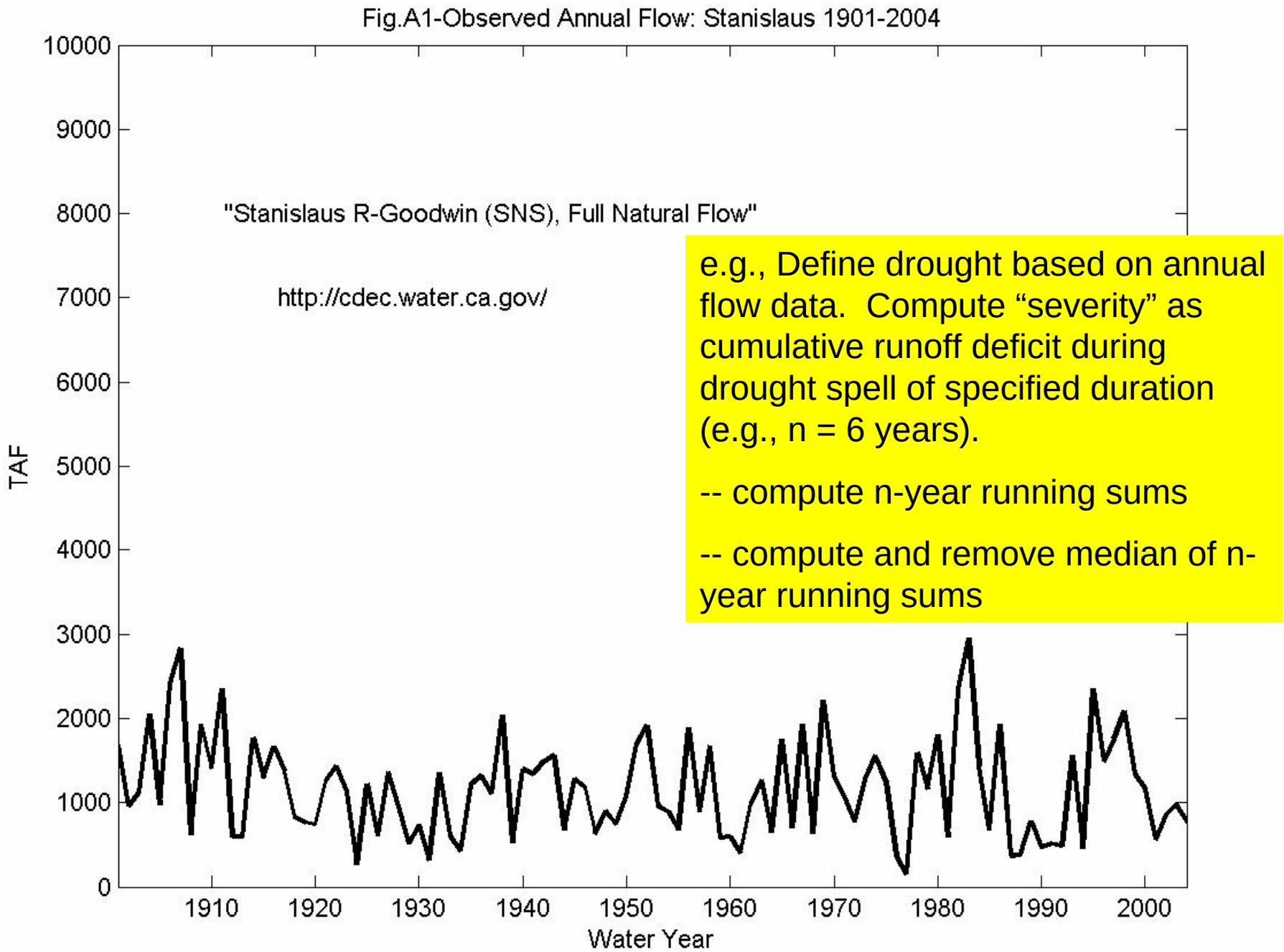
Methodology

1. Define Drought

2. Analyze reoccurrence based on observed data record

3. Analyze apparent reoccurrence based on synthetic data record



e.g., Define drought based on annual flow data. Compute "severity" as cumulative runoff deficit during drought spell of specified duration (e.g., n = 6 years).

-- compute n-year running sums

-- compute and remove median of n-year running sums

Methodology

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Information from Step #2

1. Relative severity of experienced droughts.

2. Observed reoccurrence estimates of experienced droughts.

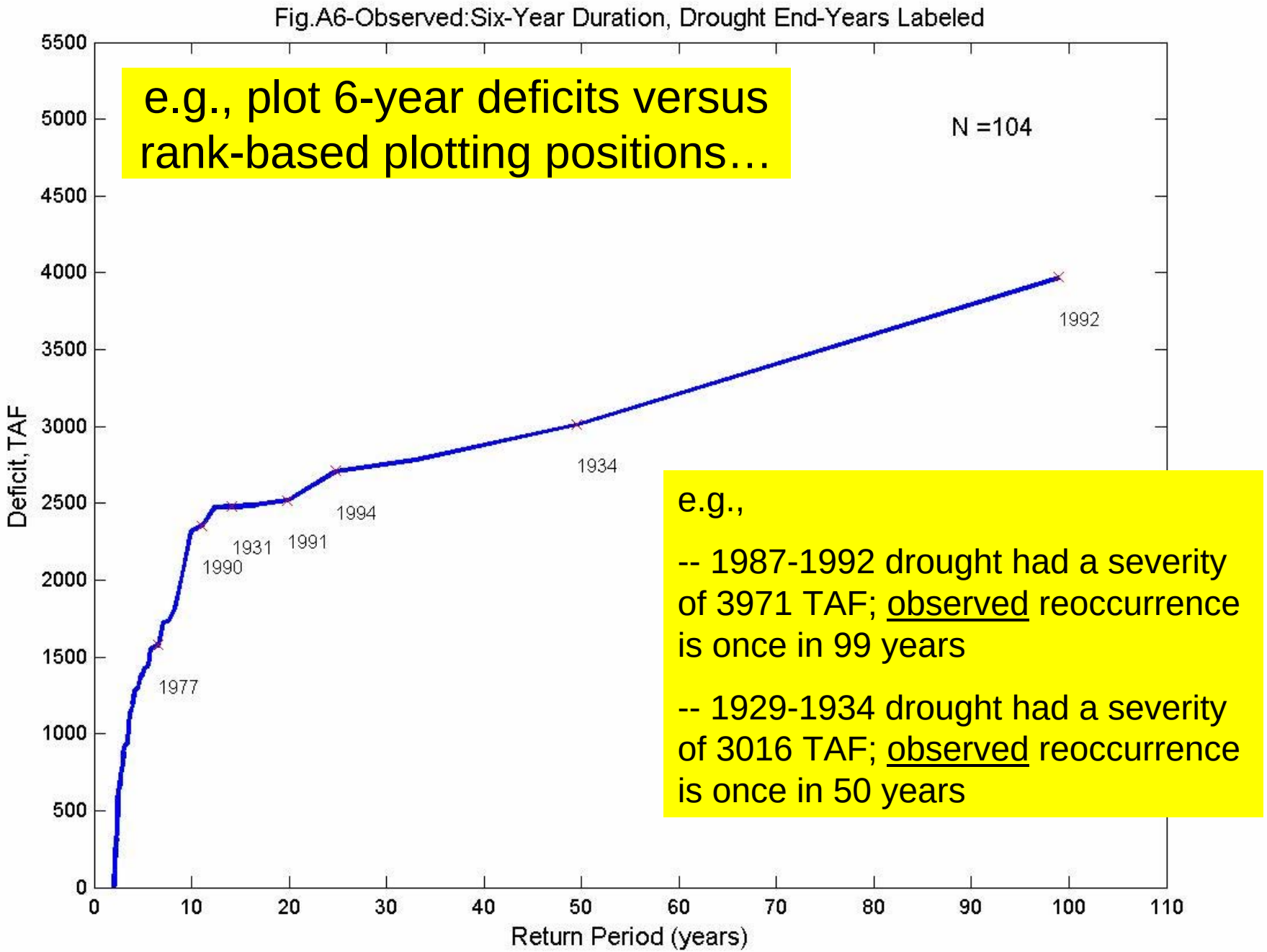
Fig.A6-Observed:Six-Year Duration, Drought End-Years Labeled
e.g., plot 6-year deficits versus rank-based plotting positions…
N =104
Deficit, TAF
Return Period (years)
1977
1990
1931
1991
1994
1934
1992
e.g.,
-- 1987-1992 drought had a severity of 3971 TAF; observed reoccurrence is once in 99 years
-- 1929-1934 drought had a severity of 3016 TAF; observed reoccurrence is once in 50 years

Do the *observations* represent the *actual* distribution of potential conditions?

Impossible to know.

But we can explore this question using synthetic analysis.

Methodology

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Modeling Observed Conditions

- What are we trying to do?
  - Model a our drought-defining condition (flow or precip)
- Why build a model?
  - Simulate a longer time series, providing a more robust basis for estimating drought reoccurrence.
- Can we believe the model?
  - Yes, if it preserves statistical properties of observations.

Step 3 – Part (a): Define Conceptual Model

- Properties to preserve:
  - persistence (auto-correlation)
  - distribution of random variations

- Initial Model:

  Synthetic Condition =

  Persistence Term + Random Term

About the Persistence Term

- Meant to address phenomena controlling persistence of multi-year dry/wet conditions.

- Potential phenomena are not understood, but we can test for their presence.

Use lag-n-year autocorrelation analysis.

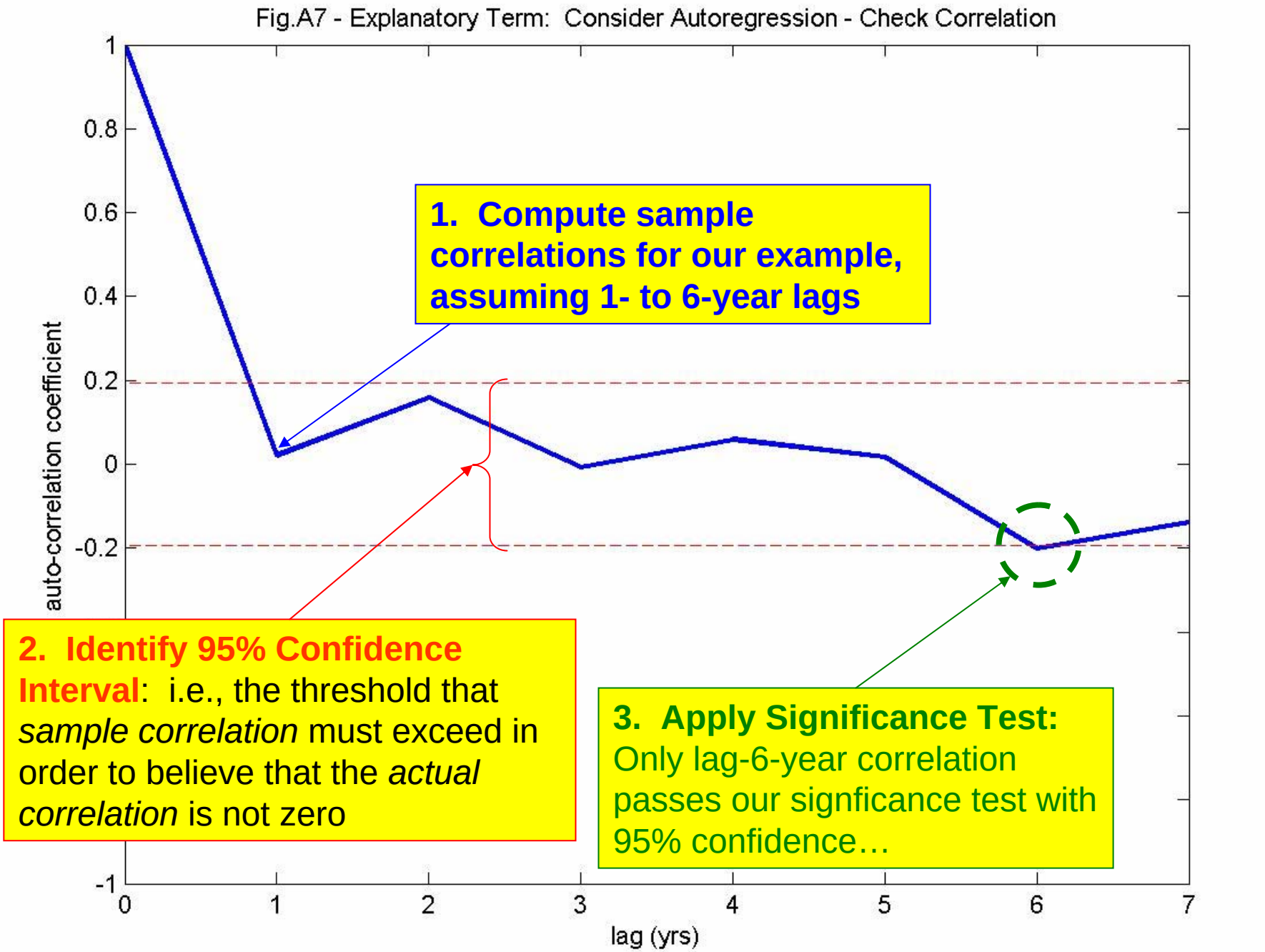
Fig.A7 - Explanatory Term: Consider Autoregression - Check Correlation
auto-correlation coefficient
lag (yrs)
1
0.8
0.6
0.4
0.2
0
-0.2
-1
0
1
2
3
4
5
6
7
1. Compute sample correlations for our example, assuming 1- to 6-year lags
2. Identify 95% Confidence Interval: i.e., the threshold that sample correlation must exceed in order to believe that the actual correlation is not zero
3. Apply Significance Test: Only lag-6-year correlation passes our signficance test with 95% confidence…

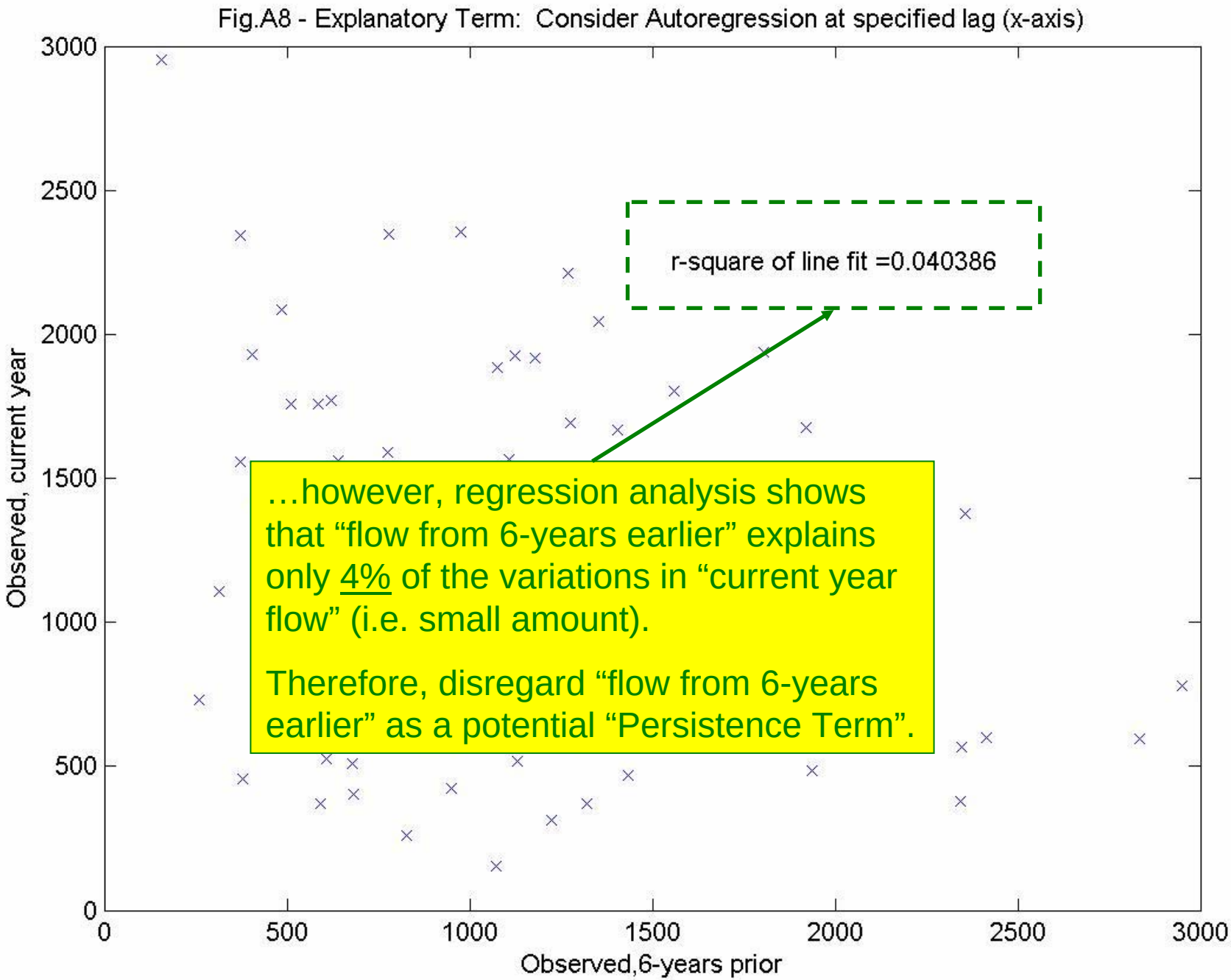
Fig.A8 - Explanatory Term: Consider Autoregression at specified lag (x-axis)
r-square of line fit =0.040386
…however, regression analysis shows that "flow from 6-years earlier" explains only 4% of the variations in "current year flow" (i.e. small amount).
Therefore, disregard "flow from 6-years earlier" as a potential "Persistence Term".
Observed, current year
Observed,6-years prior
0
500
1000
1500
2000
2500
3000

Persistence Term unnecessary...

Simplify our Model:

Synthetic Condition = Random Term

Defining our Random Term

- Fit a probability distribution to the observations
- Choose technique
  - Parametric? ← *explored*
  - Nonparametric? ← *ultimately used in this analysis*

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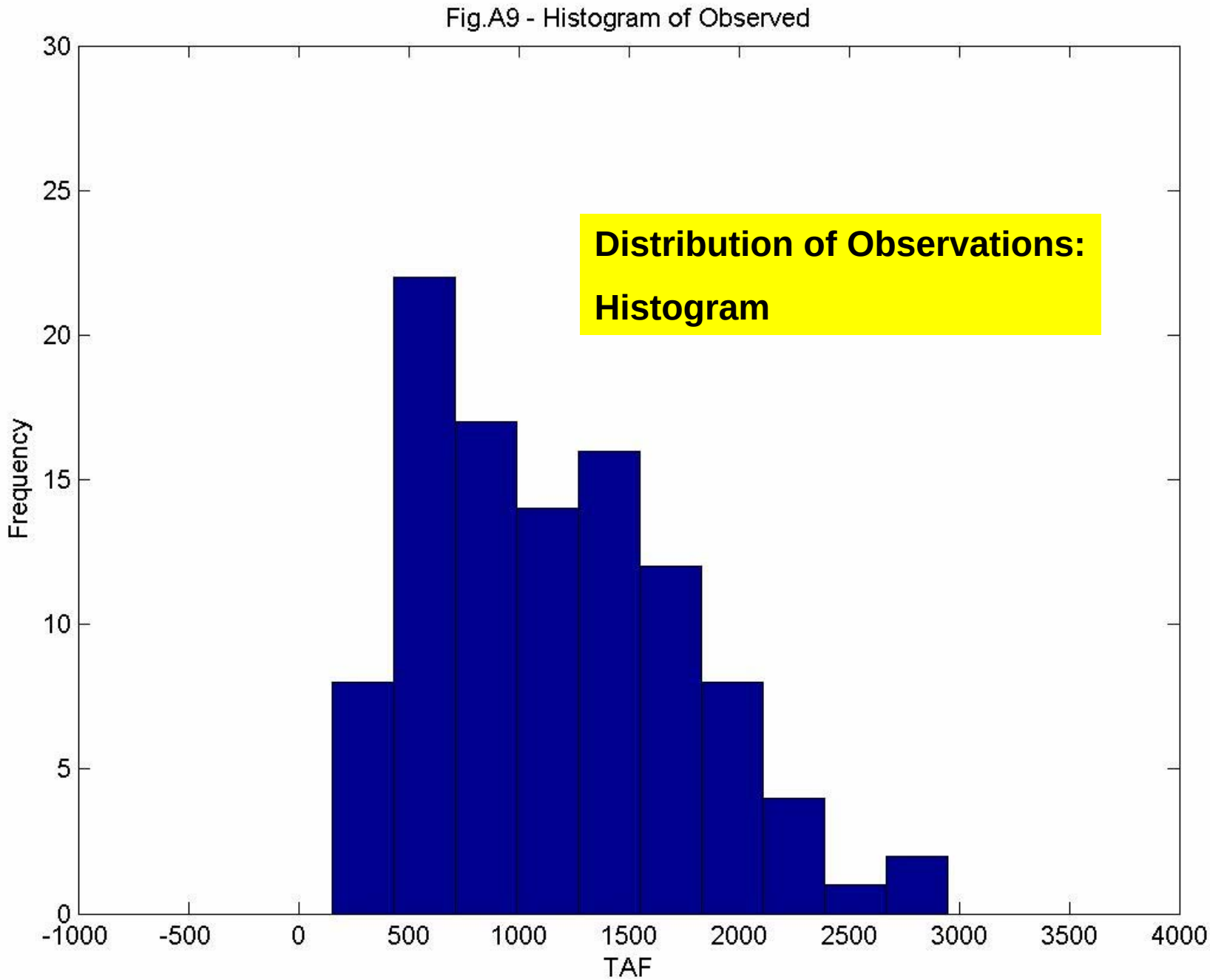
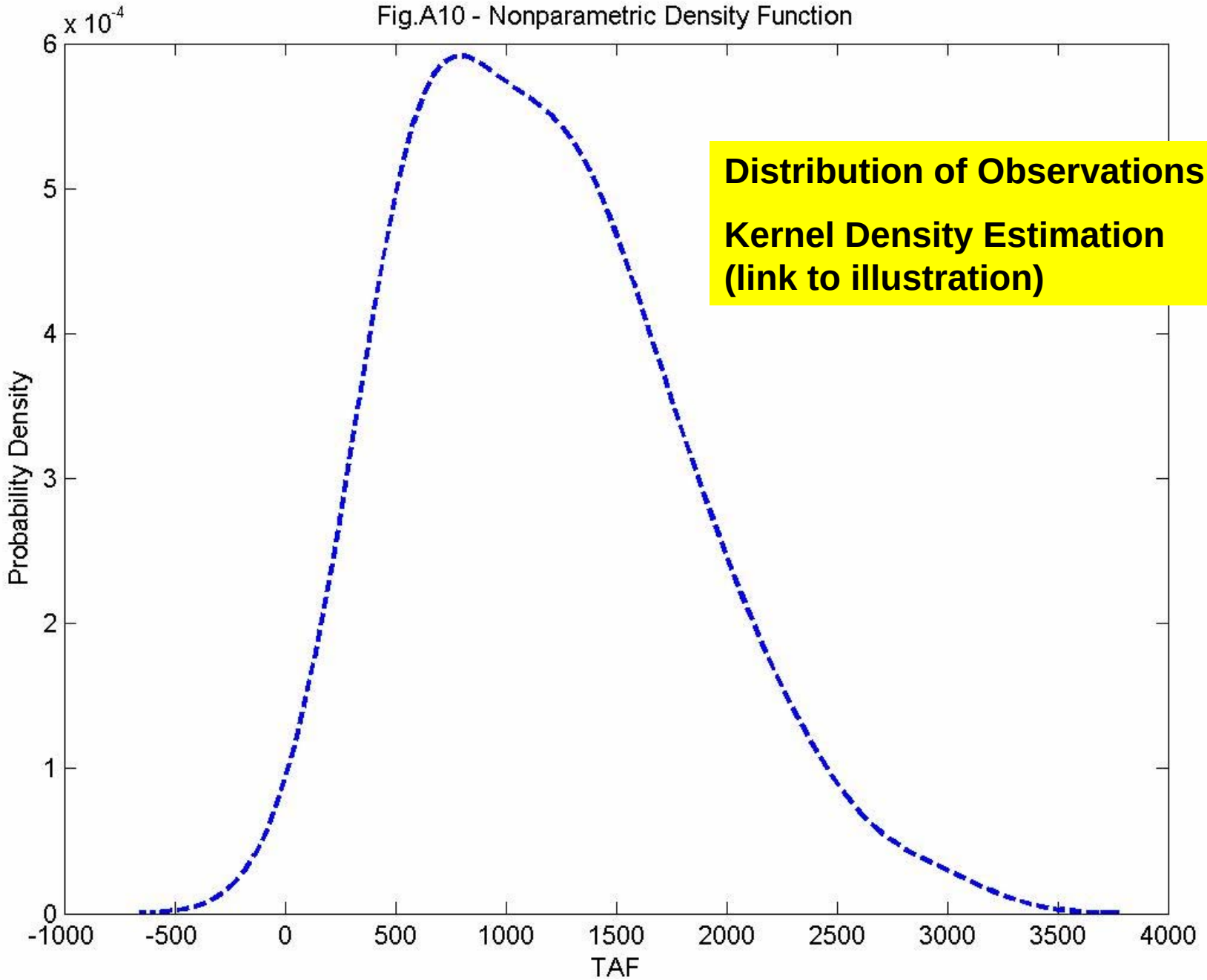


Fig.A9 - Histogram of Observed
Distribution of Observations:
Histogram
Frequency
TAF
0
5
10
15
20
25
30
-1000
-500
0
500
1000
1500
2000
2500
3000
3500
4000



Distribution of Observations:

Kernel Density Estimation (link to illustration)

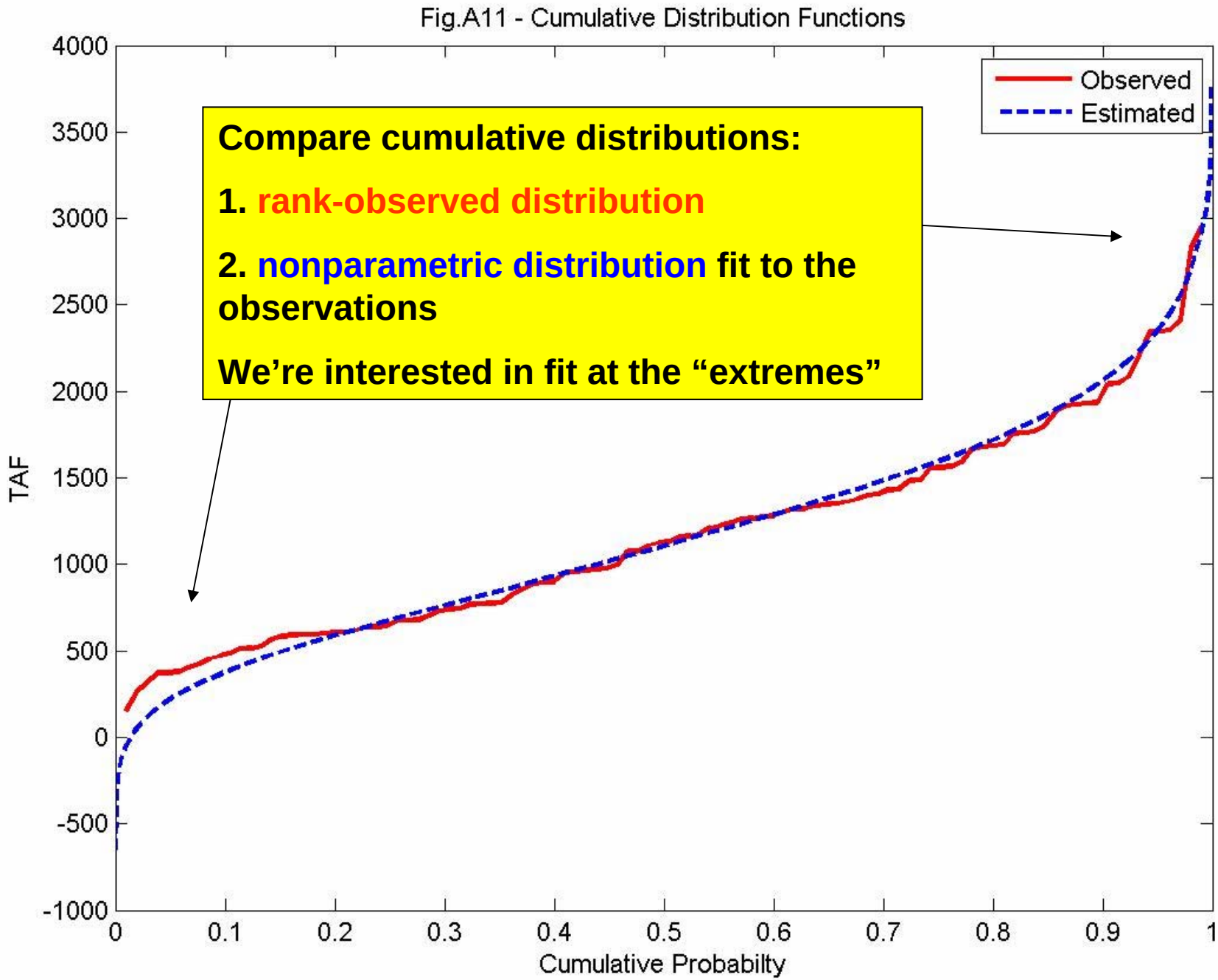


Fig.A11 - Cumulative Distribution Functions
Observed
Estimated
Compare cumulative distributions:
1. rank-observed distribution
2. nonparametric distribution fit to the observations
We're interested in fit at the "extremes"
TAF
Cumulative Probabilty
4000
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Step 3 – Part (b): Apply Model

- Generate M-year sequence of Synthetic Data
  - M = 100,000 years
  - Get sampling probabilities
    - randomly selected from uniform distribution between 0 and 1,
    - constrained to be within 0.01 to 0.99.
  - Sample M values from the nonparametric CDF fit to observations, at the M sampling probabilities.

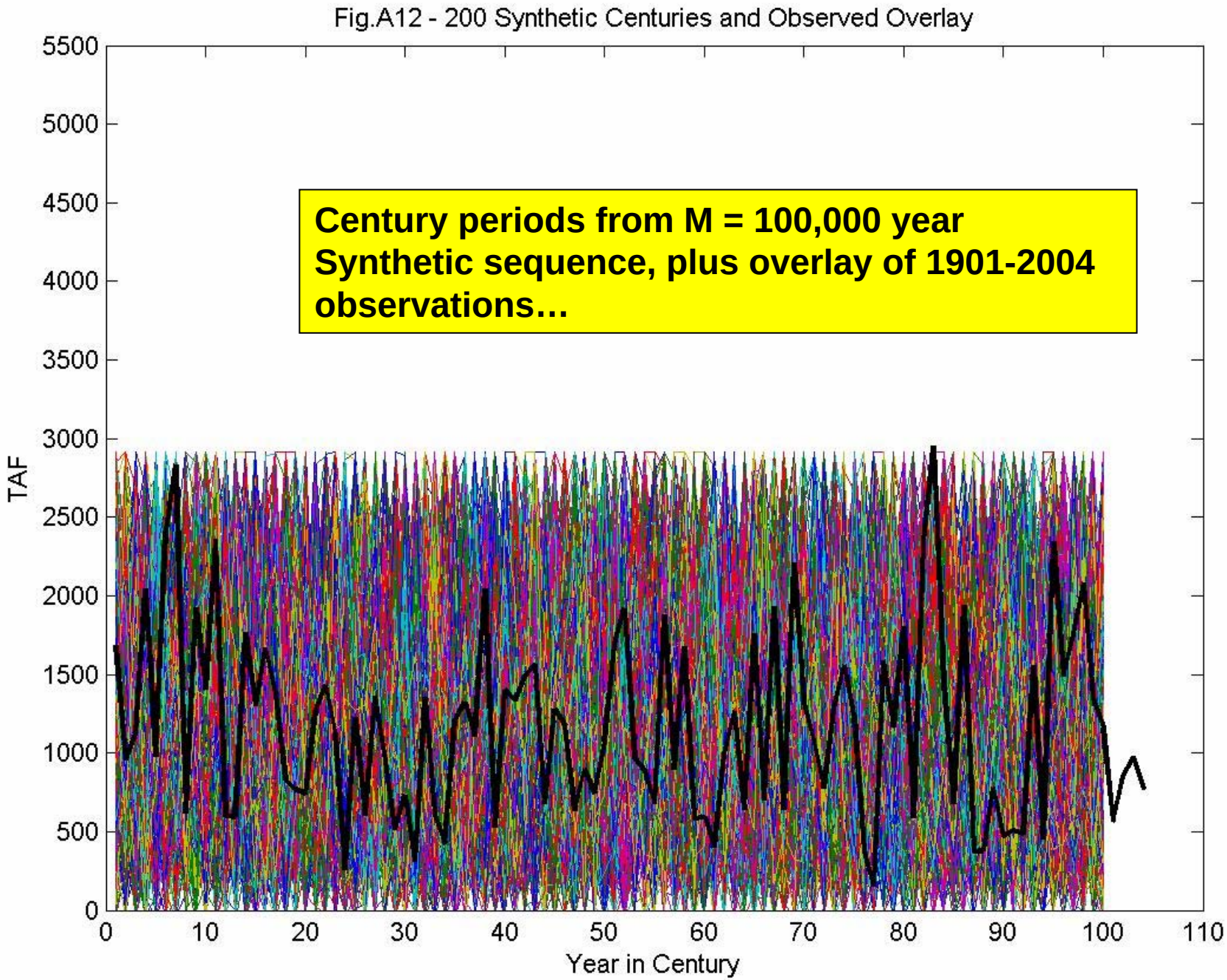


Fig.A12 - 200 Synthetic Centuries and Observed Overlay
Century periods from M = 100,000 year Synthetic sequence, plus overlay of 1901-2004 observations…
TAF
Year in Century
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
80
90
100
110

Step 3 – Part (c): Check Synthetic Distribution

- Compare:
  - Nonparametric distribution of Synthetic conditions
  - Nonparametric distribution of Observed conditions
  - They should be similar…

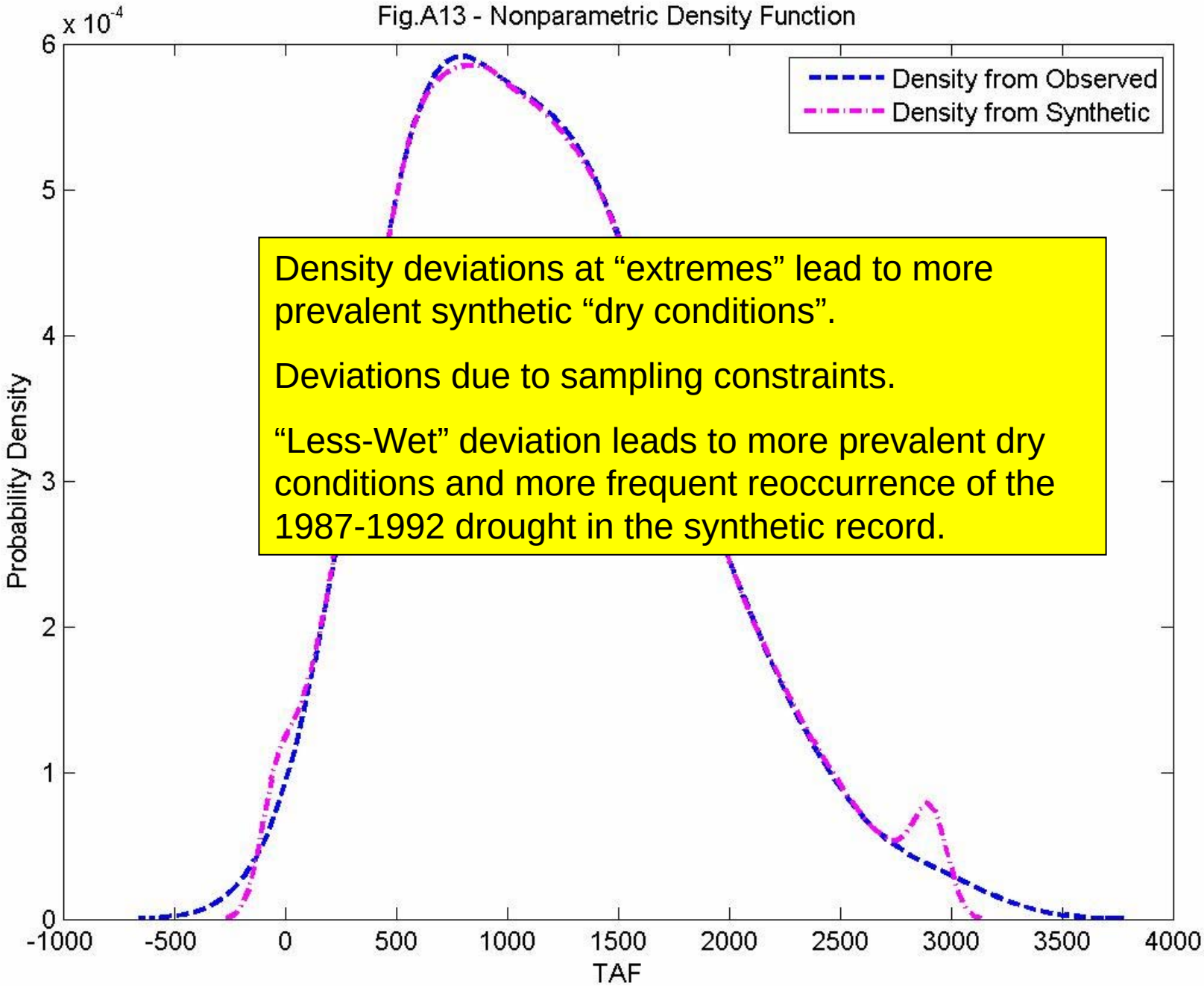


Fig.A13 - Nonparametric Density Function
x 10^-4
Probability Density
TAF
Density from Observed
Density from Synthetic
Density deviations at “extremes” lead to more prevalent synthetic “dry conditions”.
Deviations due to sampling constraints.
“Less-Wet” deviation leads to more prevalent dry conditions and more frequent reoccurrence of the 1987-1992 drought in the synthetic record.

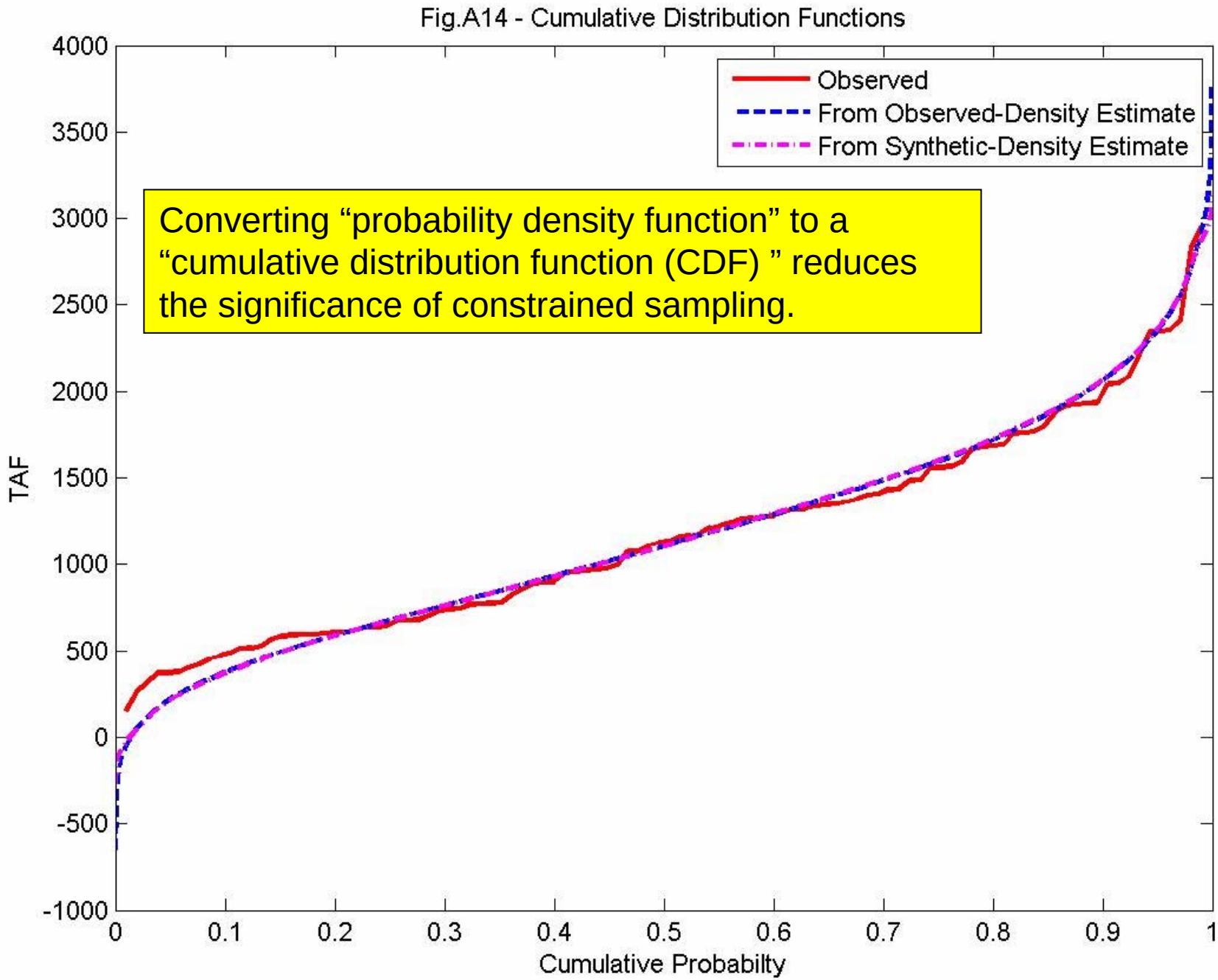


Fig.A14 - Cumulative Distribution Functions
Observed
From Observed-Density Estimate
From Synthetic-Density Estimate
Converting “probability density function” to a “cumulative distribution function (CDF) ” reduces the significance of constrained sampling.
TAF
Cumulative Probabilty
4000
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Step 3 – Part (d): Perform Drought Analysis

- Apply drought analysis procedure discussed in Step 2 to the Synthetic time series.
- Construct n-year reoccurrence distributions.
- Plot historically observed droughts on these synthetic distributions.

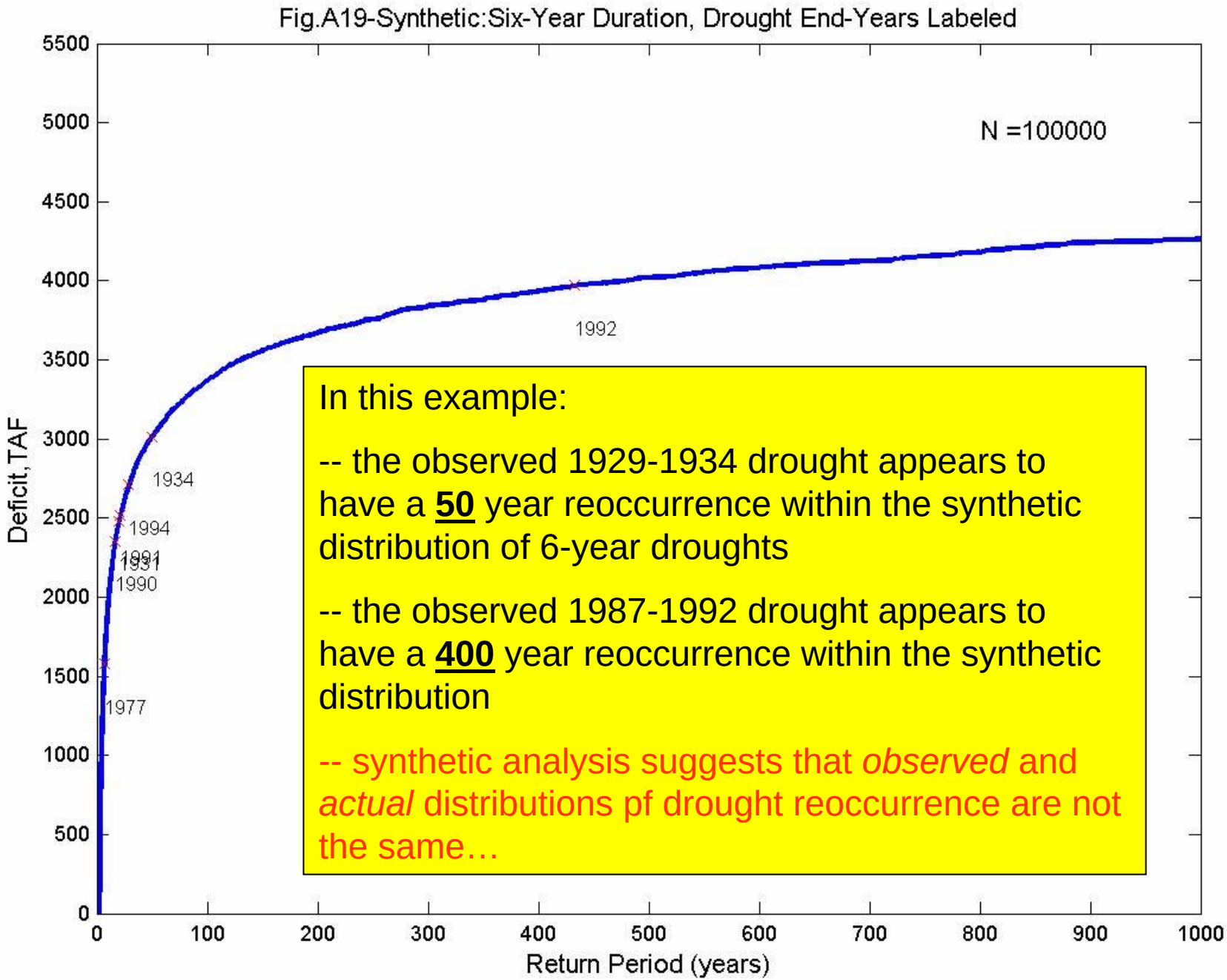


Fig.A19-Synthetic:Six-Year Duration, Drought End-Years Labeled
N =100000
Deficit, TAF
Return Period (years)
1992
1934
1994
1991
1931
1990
1977
In this example:
-- the observed 1929-1934 drought appears to have a 50 year reoccurrence within the synthetic distribution of 6-year droughts
-- the observed 1987-1992 drought appears to have a 400 year reoccurrence within the synthetic distribution
-- synthetic analysis suggests that observed and actual distributions pf drought reoccurrence are not the same…

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Purpose

- We want to explore apparent reoccurrence of the 1987-1992 and 1928-1934 droughts, varying by:
  - Hydrologic Variable
  - Period of Record
  - Site-specific versus Regional Condition

Cases

Case	Name	Variable	Period
A	Flow1	Stanislaus River, annual full natural flow	1901-2004
B	Flow2	Stanislaus River, annual full natural flow	1901-1980
C	Flow3	Stanislaus River, annual full natural flow	1906-2003
D	PrecipSOR	Annual Precipitation, “Sonora RS” CDEC I.D. SOR	1906-2003
E	PrecipYSV	Annual Precipitation, “Yosemite Valley” CDEC I.D. YSV	1906-2003
F	PrecipNFR	Annual Precipitation, “North Fork R.S.” CDEC I.D. NFR	1906-2003
G	PrecipIndex1	Annual Precip Index for American-to-UpperSJ region	1906-2003
H	PrecipIndex2	Annual Precip Index for Stanislaus-to-UpperSJ region	1906-2003

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Results: Observed Reoccurrence (yrs)

Case	Name	1929-1934 Drought	1987-1992 Drought
A	Flow1	50	99
B	Flow2	75	n/a
C	Flow3	50	93
D	PrecipSOR	31	93
E	PrecipYSV	47	93
F	PrecipNFR	31	47
G	PrecipIndex1	47	93
H	PrecipIndex2	47	93

Results: Synthetic Reoccurrence (yrs)

Case	Name	1929-1934 Drought	1987-1992 Drought
A	Flow1	50	433
B	Flow2 (note)	67	719
C	Flow3	36	258
D	PrecipSOR	25	199
E	PrecipYSV	53	68
F	PrecipNFR	20	23
G	PrecipIndex1	49	56
H	PrecipIndex2	46	108

Note: Case A observed droughts were assessed relative to the Case B synthetic reoccurrence distribution.

Response to Questions

- The 1987-1992 drought has apparent 250- to 400-year reoccurrence; 1929-1934 drought has apparent 30- to 50-year reoccurrence.

- Pre-1980 information would have suggested a 700-year apparent reoccurence for the 1987-1992 drought.

- The 1987-1992 drought seems more rare in the Stanislaus-based cases compared to regionally-representative cases.

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Critical Assumptions

- Drought definition & measurement
- Assumptions in building and applying the synthetic flow & precipitation models
  - omitting persistence
  - distribution fitting for random variations
  - constrained probabilities for distribution sampling
- Quality of observations

Summary

- Drought reoccurrence analysis was conducted for the Stanislaus River Basin region and 6-year droughts.
- Apparent reoccurrence varies with period of observed record, hydrologic variable, and monitoring location.
- Apparent reoccurrence of the 1987-1992 drought based on synthetic modeling appears to exceed “observed” reoccurrence in the hydrologic record. The synthetic and observed reoccurrence of the 1929-1934 appear to be similar.

Extras

Kernel Density Estimation used…(back)