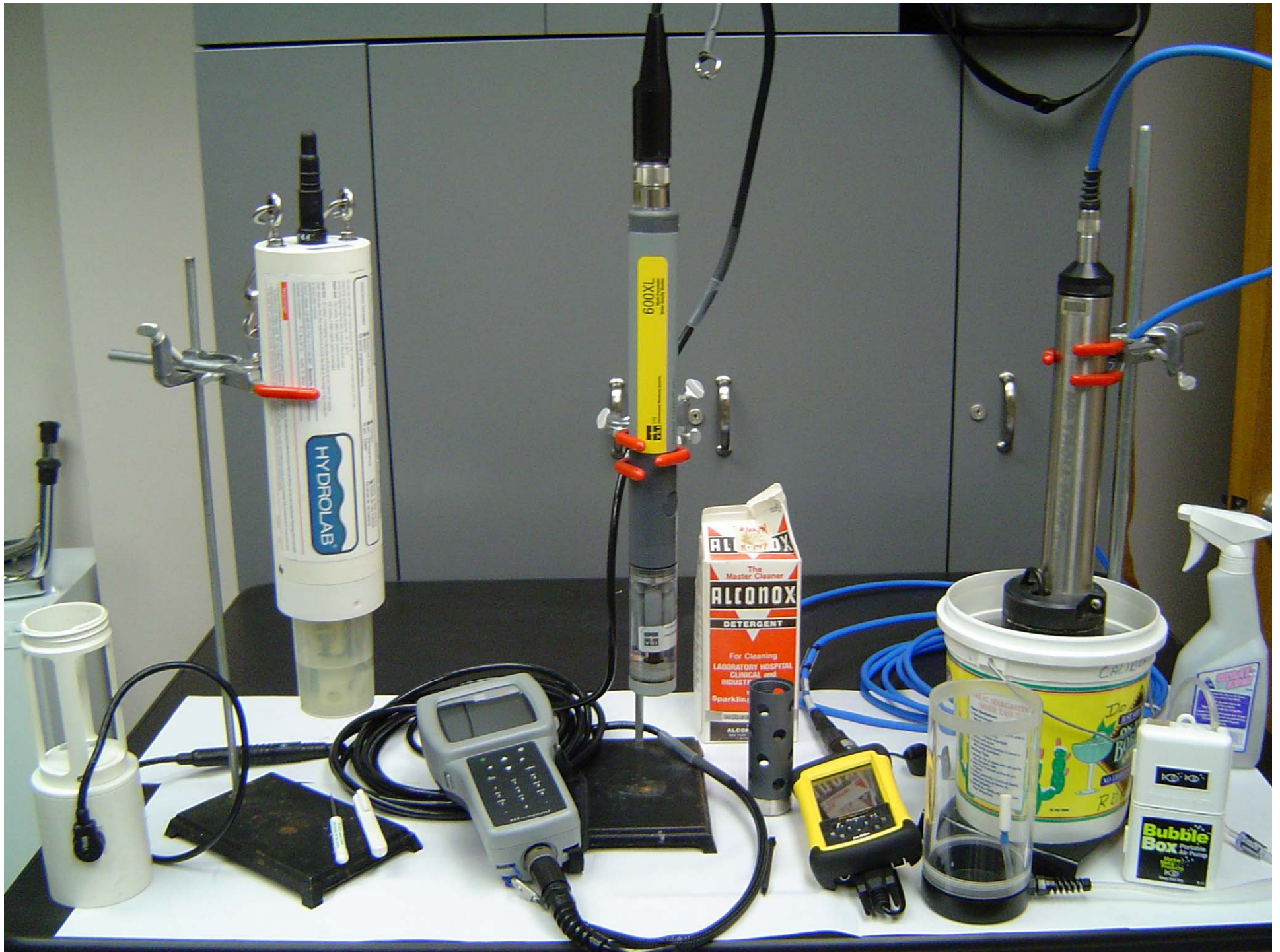# Serial Correlation and Trend Option Basics In the Era of Frequent Data Measurements

- **Roy Irwin, WRD**
- **National Park Service**
- **April 27, 2010**
- **NWQMC Denver**

What is New?

- Taking Water Quality Measurements with Sondes

- Very Frequently: Every 15 minutes, Every 15 Seconds

- Instead of Once a Month or Once a Year

A Frequent Result is:

- Much More Serial Correlation in the Data
- Biased Results for Trend Test Conclusions,
- Confidence Intervals & Other Stats
- Misleading P-values

What is Serial Correlation?

- If One Measures Too Close Together in Time or Space, Not Measuring Two Independent Samples = Autocorrelation

- The Two Measurements are Autocorrelated Only in Time, They Are Serial Correlated

- A New Measure is Not Independent of the Previous Measure

Why is This a Problem?

Violates Independence Assumption of Many Statistical Procedures.

Sample Size (n) is for Independent Samples

If Your Samples are not Independent, n is Artificially High and p-values Artificially Low

What Kinds of WQ Data Are Serially Correlated?

- Often: Monthly and Especially More Frequent Water Column Data
- Sometimes: Even Less Frequent Groundwater Quality or Levels, Sediment quality, Tissue Contaminant Concentrations, or Large Lake Water Levels
- When in Doubt, Check.

Solutions at Four Levels of Complexity

- From Most Simple to Most Complex
- Really Easy Solutions for Beginners
- Trend Tests Solutions for Those with Intermediate Experience
- Identifying Serial Correlation Basics with Correlograms and Tests
- Advanced Model Fitting Methods

We Will Concentrate on the Simple Options

- For More Complex and New Trend Approaches, Go to the Advanced Trend Discussions at This Meeting

- Including Trend Sessions This Afternoon Led by Hirsch, Lorenz, Vecchia, and Paulsen

- And Trend Sessions Tomorrow

Complexity Level One

- For Absolute Beginners Who
- Don't Have the Time or Inclination to Learn More About
- Serial Correlation or More Complex Trend Test Options
- Question: How Frequently to Measure?

Plot Different Frequencies, Per Kirchener et al. (2004):
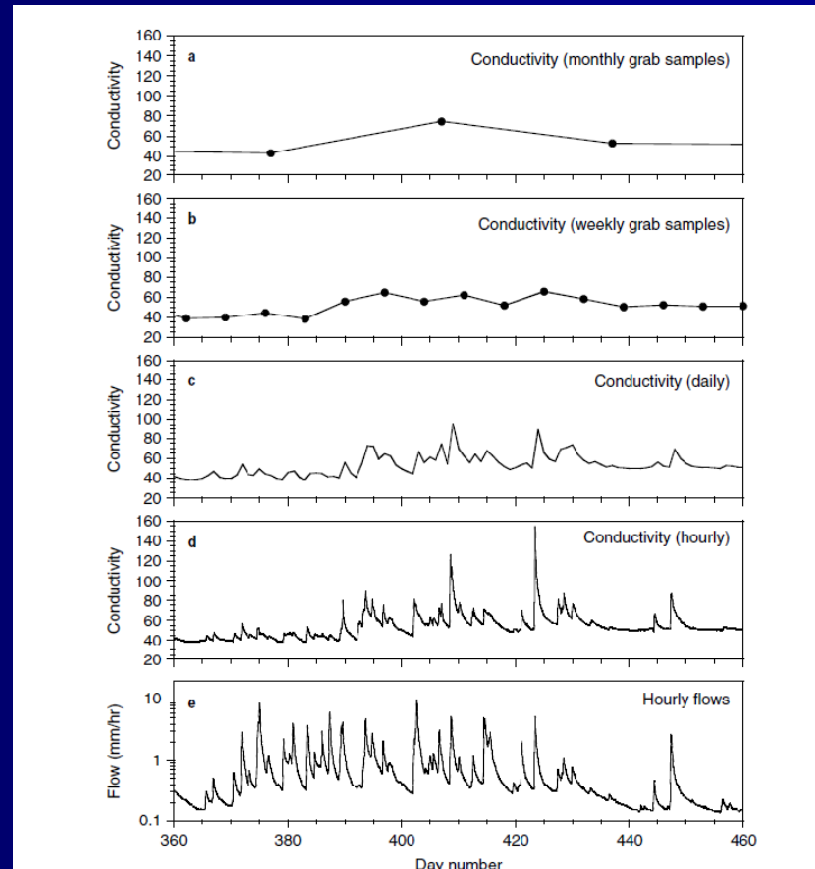
Hints From That Plot

- If You Want To Correlate Conductivity To Flow, One Could Use Hourly Values, Hourly Medians, Or Perhaps Daily Medians.

- Correlation Was Stronger During The Later Parts Of The Record.

- But Trying To Link Hourly Flows And Monthly Conductivity = A Problem.

The Complete Census Option

- Measure so Often You Essentially Have a Complete Census for That Site
- When Comparing Plots of More and More Frequent Measures
- At What More Frequent Intervals Do the Plots Stop Changing Shape?
- Every 5 or 15 Seconds = Usually a Complete Census (Signals Don't Change Faster)

If One Has a Census

- One Has Less or No Need For Complicated Trend Tests, Confidence Intervals, or Other Complex Statistics

- Less or No Need to Be Concerned About Serial Correlation

- The Mean is Exactly the Mean

- Only Uncertainty in a Change = Single Measurement Uncertainty

When Looking at the Frequency Option Plots

- Also Decide if There Are New Questions Only More Frequent Data Can Answer

- How Many 30 Minute Periods Per Year Exceed A Water Quality Standard and/or Is There A Trend In The Number Of Such Periods Over A 10 Year Period?

- Can't Use Monthly Data For That

Which is More Important to a Fish?

- The Average Yearly pH, or

- The Number of Consecutive 30 Minute Periods that pH Consistently and Constantly Exceeded 9.5?

- The New More Frequent Data Can Answer New and More Biologically Relevant Questions

Then Choose the Most Frequent Measurements

- That are Logistically Feasible
- & Help Answer Questions
- That Can be Done at the Same Frequency as Driver (Explanatory) Variables
- Finally, Have A Statistician Help with Data Analysis

Complexity Level 2:

- **Perform Additional EDA Plotting for Longer (1, 5, and 10 year) Periods**
- **With Smoothed Trend Lines (LOWESS or LOESS)**
- **To Look for Hints of Monotonic (One Way) Trends, or Regular Cycles that Reverse**

If the Hint is Monotonic

- Look For Long Term (10+ year) Trends in Monthly or Seasonal Medians Using

- Seasonal Kendall (SK) or

- Seasonal Kendall Trend Test for Data with Serial Dependence Within Seasons (SKSD)

If Plots Not Monotonic
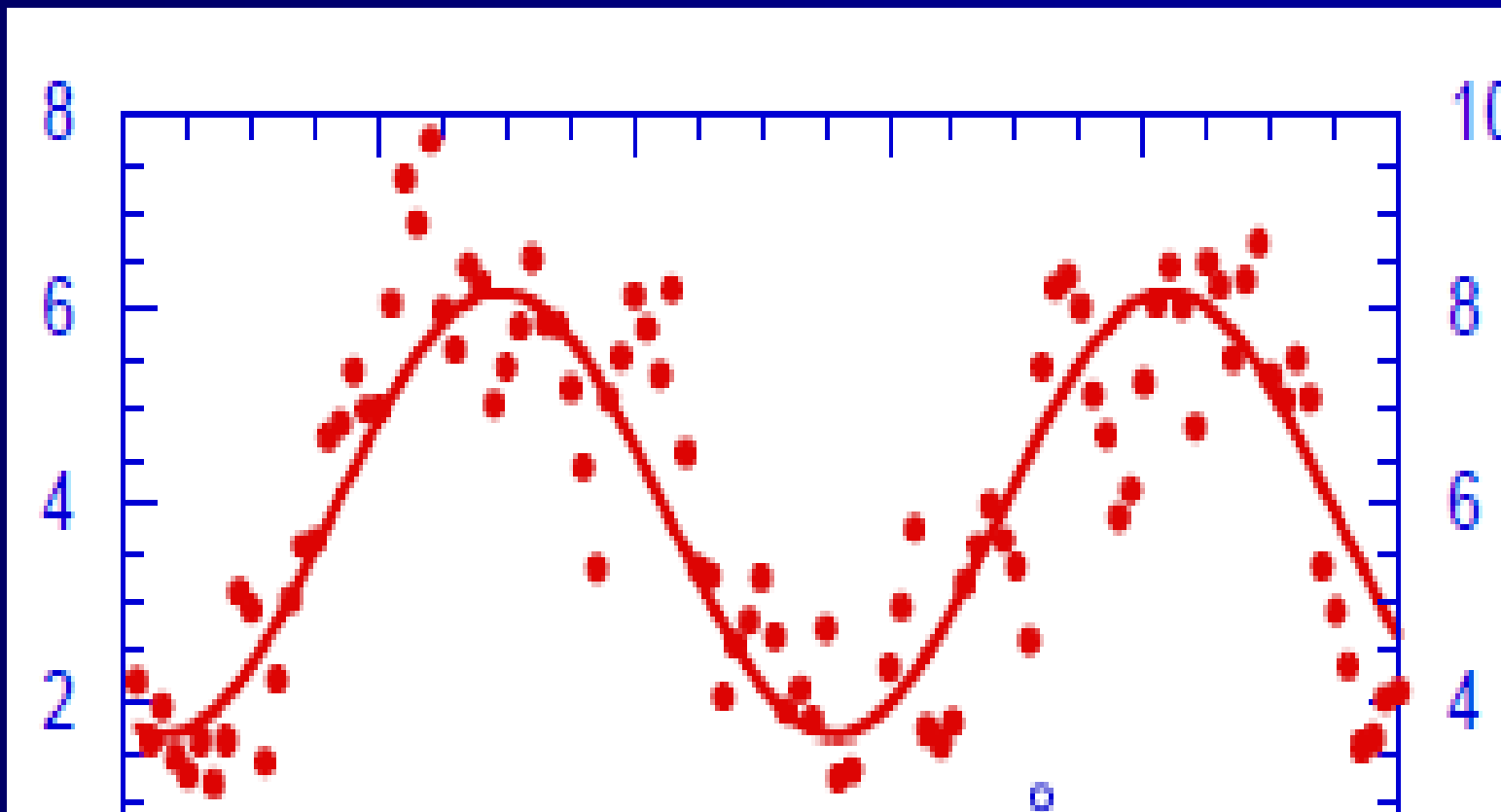
Just Describe the Pattern

- One Doesn't Always Need a Trend Test!

- A Resource Manager Needs to Know What the Pattern Is, Not Just Whether or Not a One-Way Trend Occurred

- Consider Getting Help to Do Quadratic Trend Test or other Complex Methods

**Complexity Level 3: Using Correlograms and Simple Tests to Assess Serial Correlation**

- To Answer the Question: Is There Serial Correlation in My Data?

- Construct a White Noise Correlogram with Horizontal Confidence Intervals

White Noise Vs Large Lag Standard Error Correlograms

- Only Difference is How the Confidence Interval Lines are Drawn

- To Test for Absence of Serial Correlation (White Noise), CI =

- ± 2/Sqrt of n = Rough Approximation

- Large Lag Standard Error = Longer Equation, Answers Different Question

White Noise Vs Large Lag Standard Error Correlograms, Courtesy D. Meko, University of Arizona
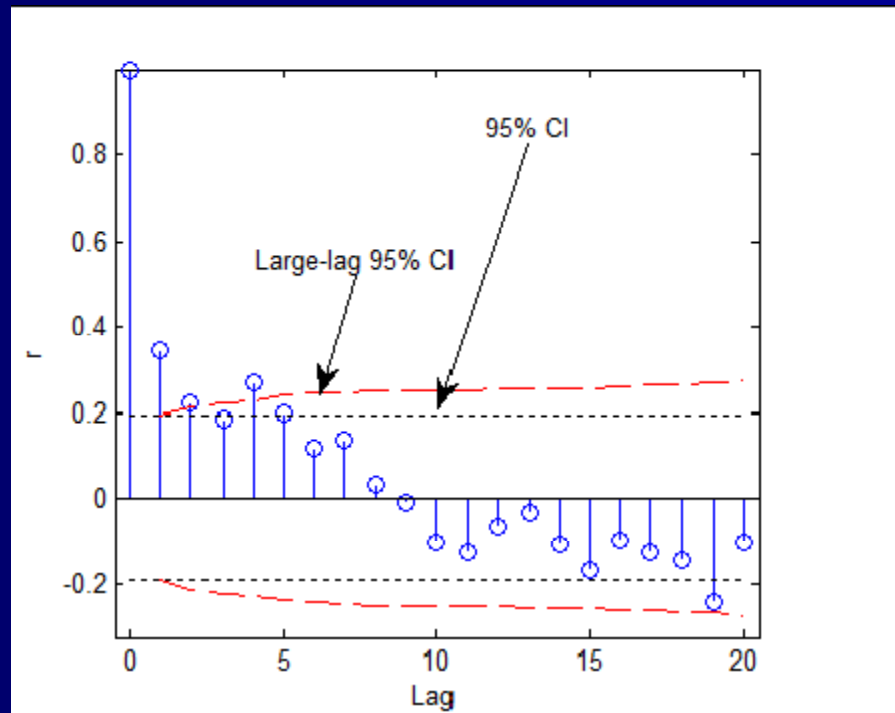
At What Lag Does the Serial Correlation Disappear?

- Construct a Large-Lag Standard Error Correlogram With an Expanding Confidence Interval

- In Previous Slide, Lag 4 is the Last Lag Extending Above the 95% CI Line

- If We had Used Rough Approximation, Less Correct Answer = Lag 5

White Noise Vs Large Lag Standard Error Correlograms, Only Difference = CI Line
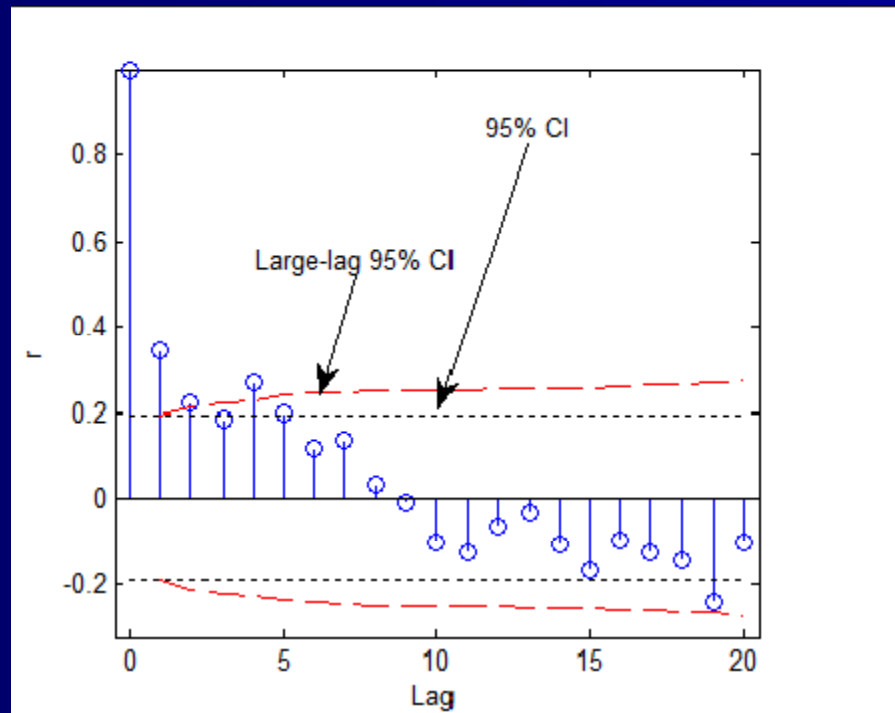
Is it First-Order Serial Correlation Only?

Partial Autocorrelation
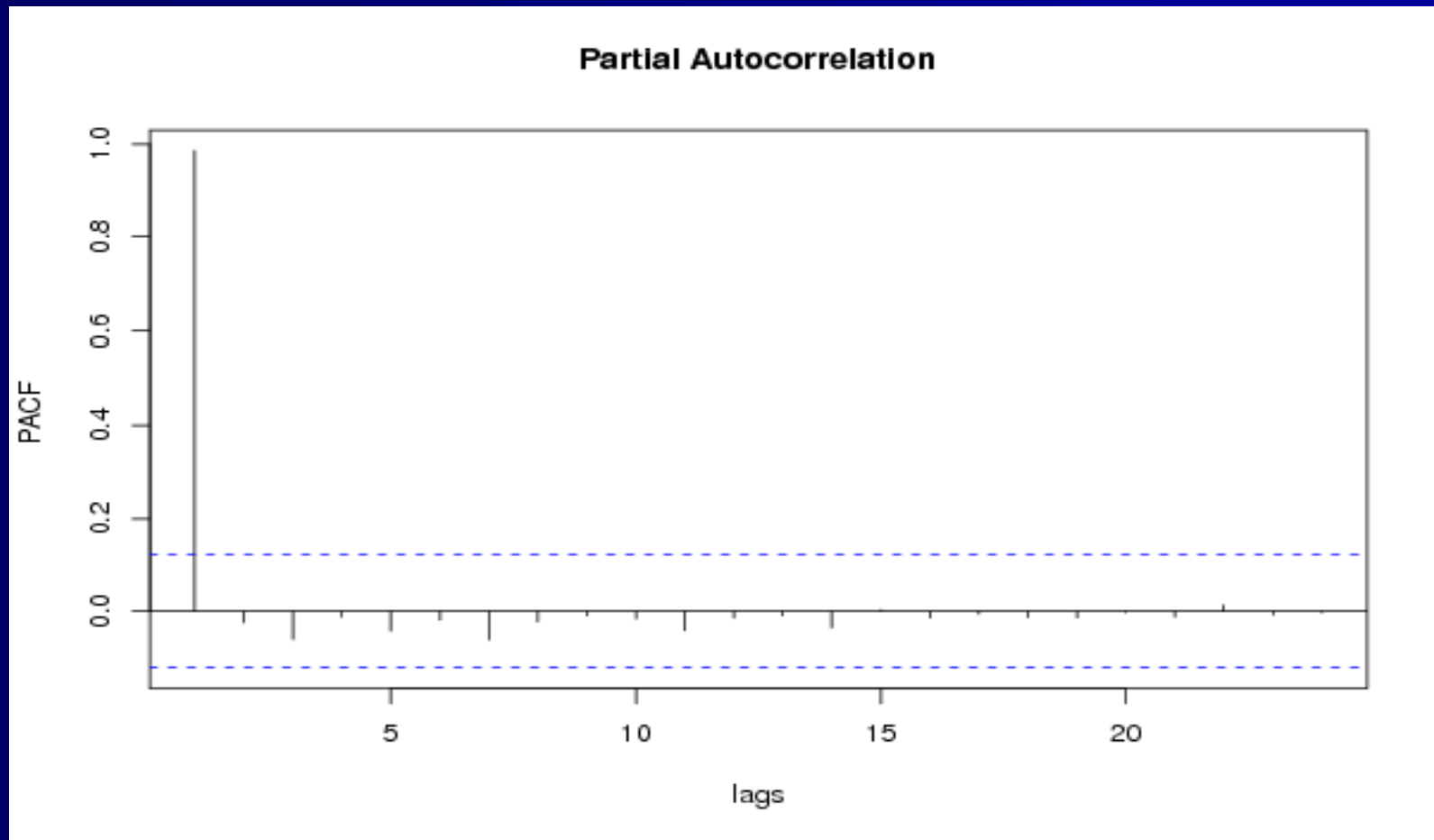
Hint from This Line of Evidence:

- First-Order Serial Correlation
- Possibly Fits an AR(1) Autoregressive Model, However --------
- In All Things Related to Serial Correlation and Trends, Try to Look From More than One Angle & Scale
- Options Include the Following

Specialized Tests for First-Order Serial Correlation

- Durbin-Watson Test
- To Test for First-Order Serial Correlation
- Commonly Used In SAS and Matlab
- In R Software, One Can Use the dwtest function in the lmtest package
- Kendall Tau Test: 2nd Line of Evidence

Durbin-Watson Cautions

- Sometimes Inconclusive
- Some Say Not to Use it With Lagged Dependent Variable
- They Suggest Using bgtest command in R instead to calculate Breusch-Godfrey test

Why Multiple Lines of Evidence?

- Most of these methods are approximations only
- Durbin-Watson Has Three Possible Outcomes
- Reject, Fail to Reject, or the Test is Uncertain

Effective Sample Size

- If the Partial Autocorrelation Coefficient Correlogram Suggests Only First Order Serial Correlation

- Use (Relatively) Simple Equations to Estimate Effective Sample Size and Use that in Confidence Intervals and other Complex Statistics instead of N.

Then Use the Serial Correlation Information

- To Guide Trend Analysis Decisions.
- Easy Options:
- Use Information To Decide How Much "Extra" Information To Discard And Then Use Only Less Frequent Regular Data Points, Or Simplify The Data To Daily Medians, Or Seasonal Medians.

More Complex Methods

- Go To The Other Trend Sessions At This Conference
- Consider Seeking Statistical Help
- An Acronym Alphabet Soup Of Many, Many Complex Options.
- Try To Make Sure The Option Fits The Type Of Data And Questions You Have.

Alphabet Soup of Complex Trend Methods

- Acronyms Include: acronyms including (but not limited to) methods referred to as: GLE, GLIM, ARMA, ARIMA, CUSUM, GLS, GAM, GLM, MA, MLM, ANOVA, ANOSIM, PerMANOVA &

- Trend Methods for Data with NonDetects: MLE/TOBIT, & ATS

- Beginners: Ask for Expert Help

For More Information, See

- NWQMC Electronic Decision Tree Being Developed by the Statistics Subgroup
- Free SK and SKSD Trend Tests Available from NZ: http://www.niwa.co.nz/our-science/freshwater/tools#analysis
- Free ACF and PACF Correlogram Calculator With the Right Confidence Intervals at http://www.wessa.net/rwasp_autocorrelation.wasp