Estimating trends in ENSO with Darwin SLPA

Century-length versus multi-decadal perspectives, and issues with trend significance in red-shifted time series

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Motivation

- Use a high quality, century-length (135yr) record of marine climate to illustrate issues faced in trend studies.

- Revisit the issue of whether or not there is evidence of long-term change in the El Nino-Southern Oscillation (ENSO)

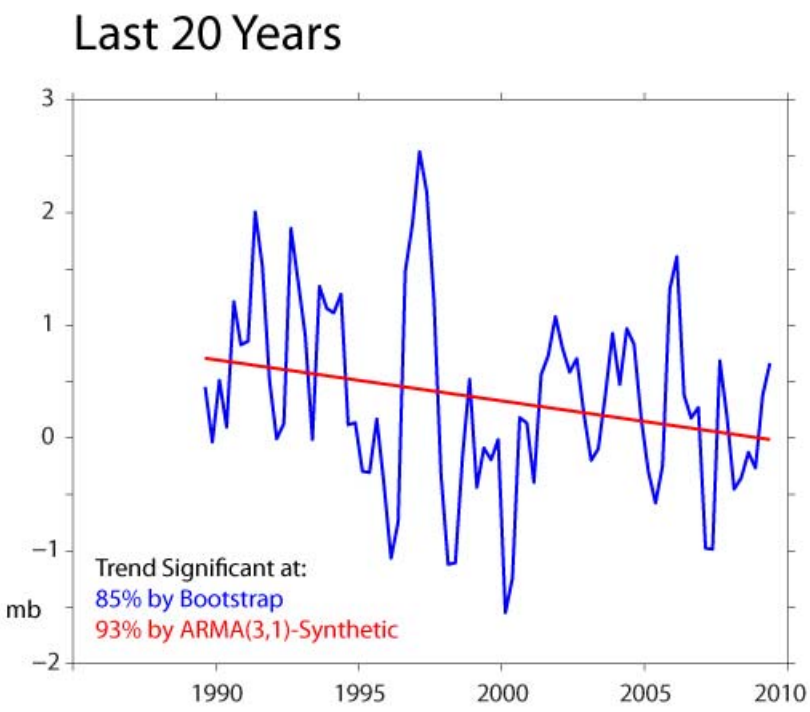
Outline

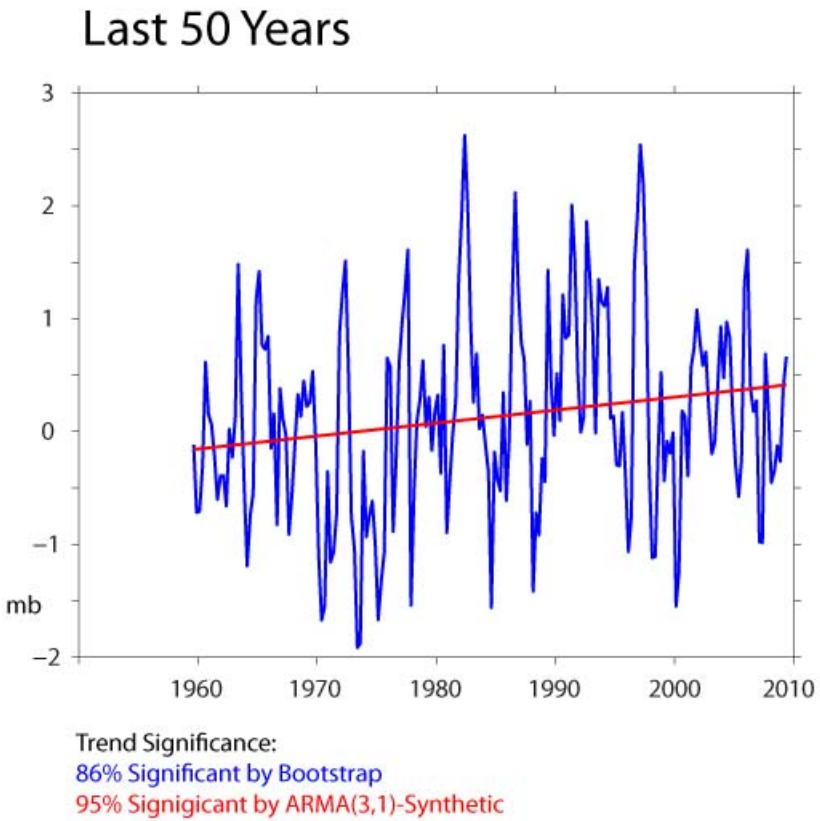
1. Results
2. Background
3. Trend statistical significance with synthetic (known) time series
4. Long-term trend in Darwin
5. Multi-decadal variability in Darwin

Some Results First

•The long-term trend in Darwin is not statistically significant (p>20%) by even the most lenient trend significance test considered.

•Despite this, many multi-decadal trends are statistically significant, but can be positive or negative.





Background: ENSO and Darwin

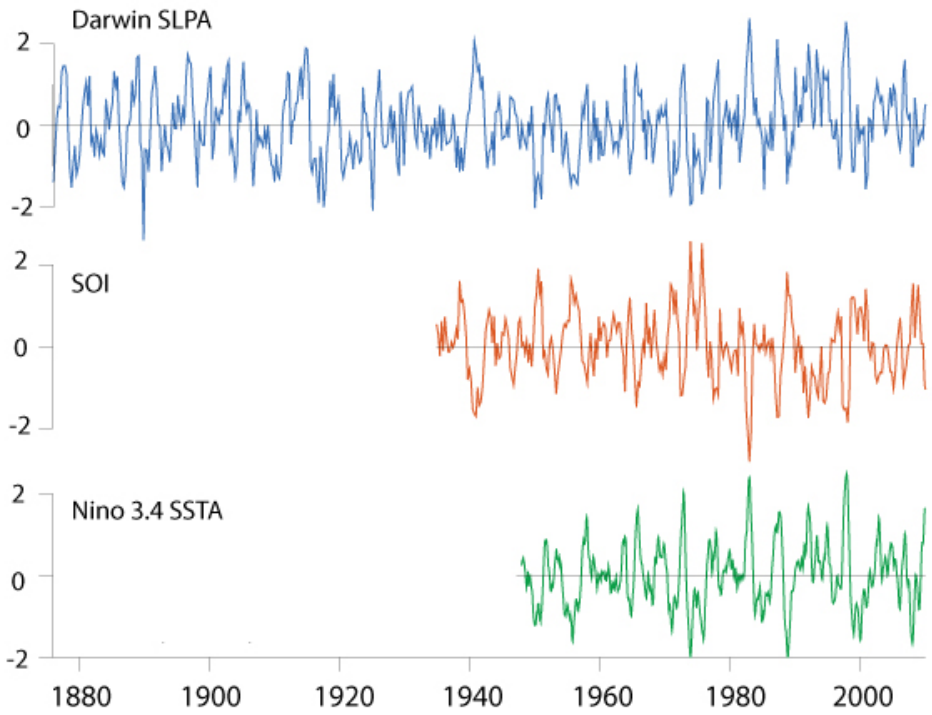
•Darwin SLPA is a good proxy for ENSO state

Darwin SLPA is highly correlated with other ENSO records at periods > 5yrs (r=0.85 and 0.9, for SOI and Nino 3.4)

•Previous studies suggested there is evidence of climate change in Darwin record (e.g. Trenberth & Hoar, 1996).

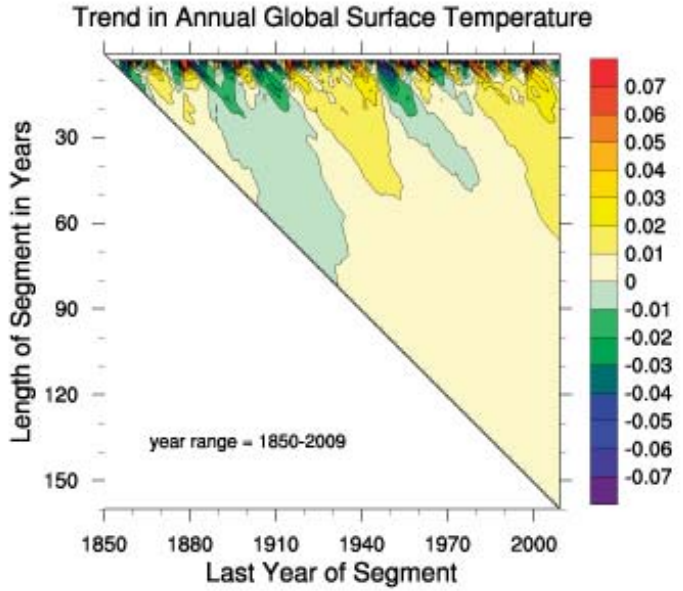
• Nicholls (2008) found ENSO seasonality has not changed, but there is a 50yr trend in SOI in some seasons.

•IPCC model projections of future ENSO trends differ (Vecchi, 2008)



Background: multi-decadal and century-length trends

- Need for understanding relationship between relatively short and long term trends has been recognized
- Visual tool suggested by Leibmann et al. (2010)
- Interest here is in seeing how this plays out for a different type of variable – trend significance methods from Liebmann et al. do not apply to Darwin SLPA.



From: Liebmann, et al., BAMS, 2010

Question: Are trends over short records representative of longer term behavior?

- We often look for trends in climate variables over the full-length of the available historical records.
- Yet, we are often ultimately interested in trends over longer periods.
- Question: Can trends at one timescale be considered representative of longer term behavior in geophysical time series?

Does determining trend statistical significance provide the answer?

- We often look to statistical methods to guide our interpretation of a given trend.

  "significant" = indicative of change in underlying processes

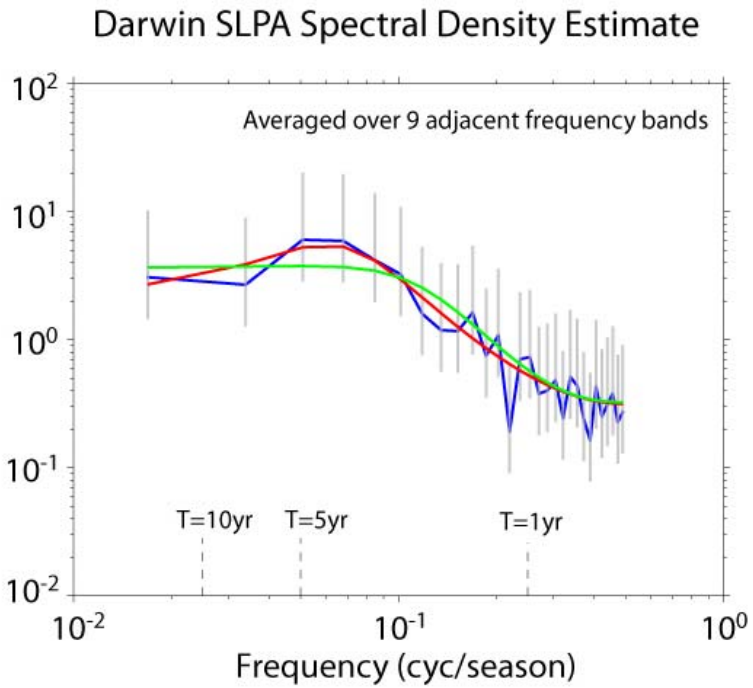
- But, reliably determining trend statistical significance can be discouragingly difficult for many geophysical time series, which are characteristically "red-shifted"

Trend Statistical Significance

Monte Carlo Experiment Procedure:

1. Generate synthetic time series with no long-term trend
2. Estimate information needed to perform trend significance test from de-trended time series [T_o for t-test, bootstrap, 5 parameters for ARMA(3,1)]
3. Tabulate rate of finding false statistically significant trends over large number of trials (ideally, the false-positive rate should match the nominal test confidence interval)

Monte Carlo Test: Step 1
Choosing Representative Synthetic Time Series



ARMA(3,1) Model

$y(t) = a_1\, y(t-1) + a_2\, y(t-2) + a_3\, y(t-3) + x(t) + b\, x(t-1)$

a = [1.372, -0.466, -0.061], b = -0.736, σ = 0.635

a = [0.829, -0.157, -0.067], b = -0.184, σ = 0.653

Step 2: Choosing Trend Significance Tests

Tests	Assumption	Information Needed
Student's t	Gaussian distribution	Needs to know number of "degrees of freedom". This is estimated from sample time series.
Bootstrap	Sample distribution represents full distribution	Same as above
ARMA model	Form of model represents the real process	Number and values of parameters [5 for an ARMA(3,1) model]

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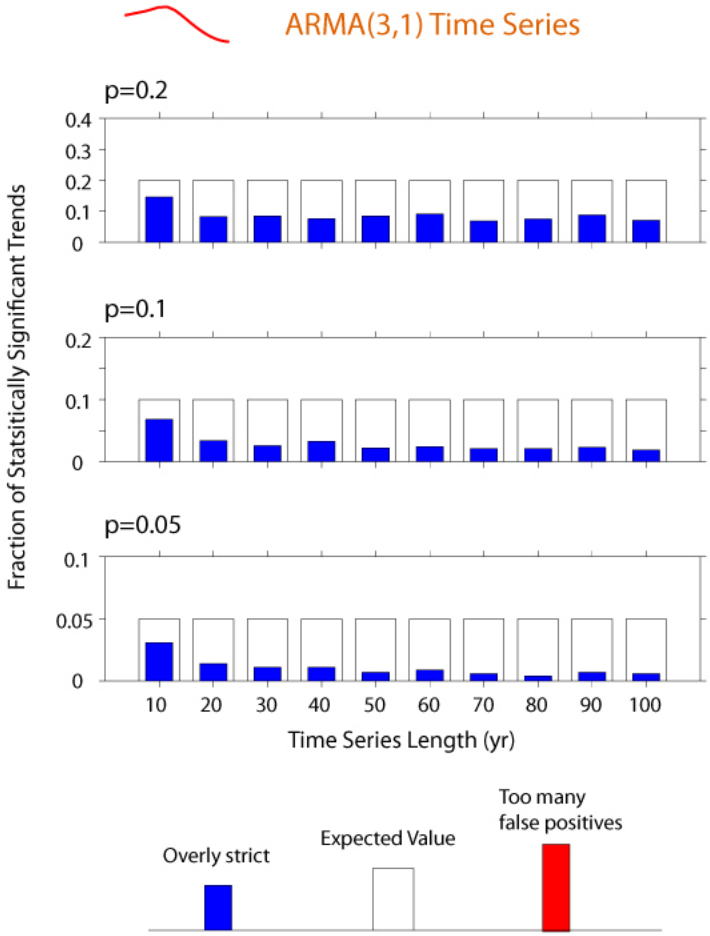
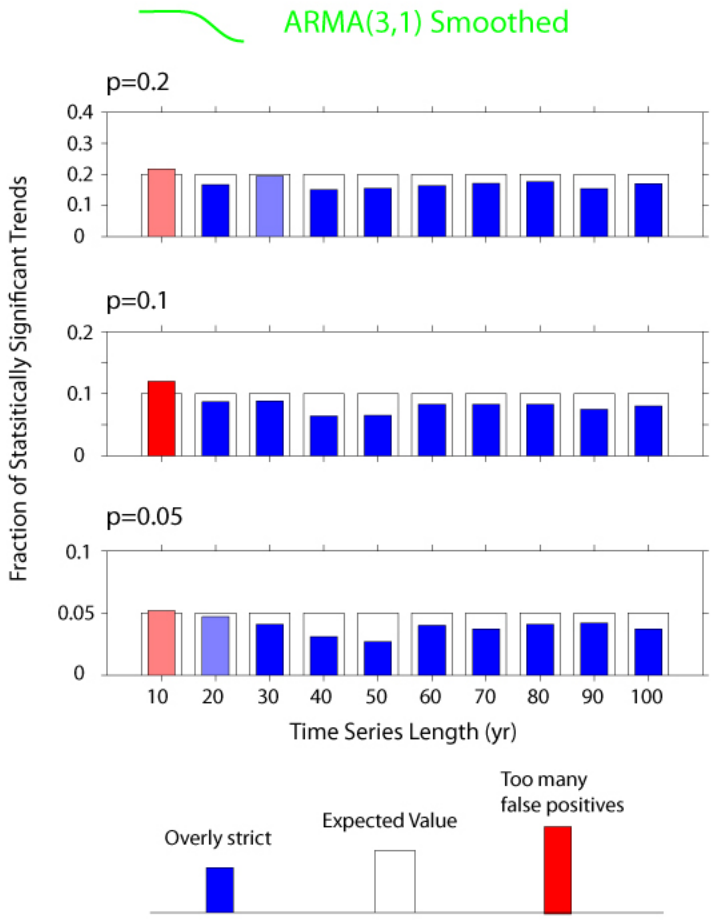
Monte Carlo test results

- Student's t results

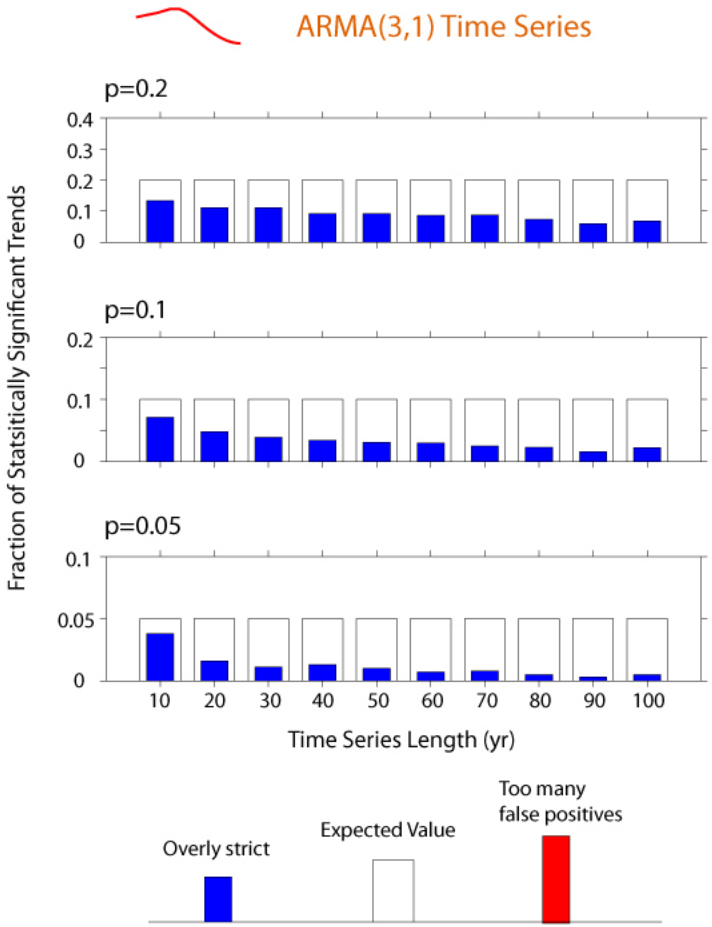
Too strict in one case, about right in the other = unable to find a test that is reliable for all behaviors consistent with 135yr Darwin record

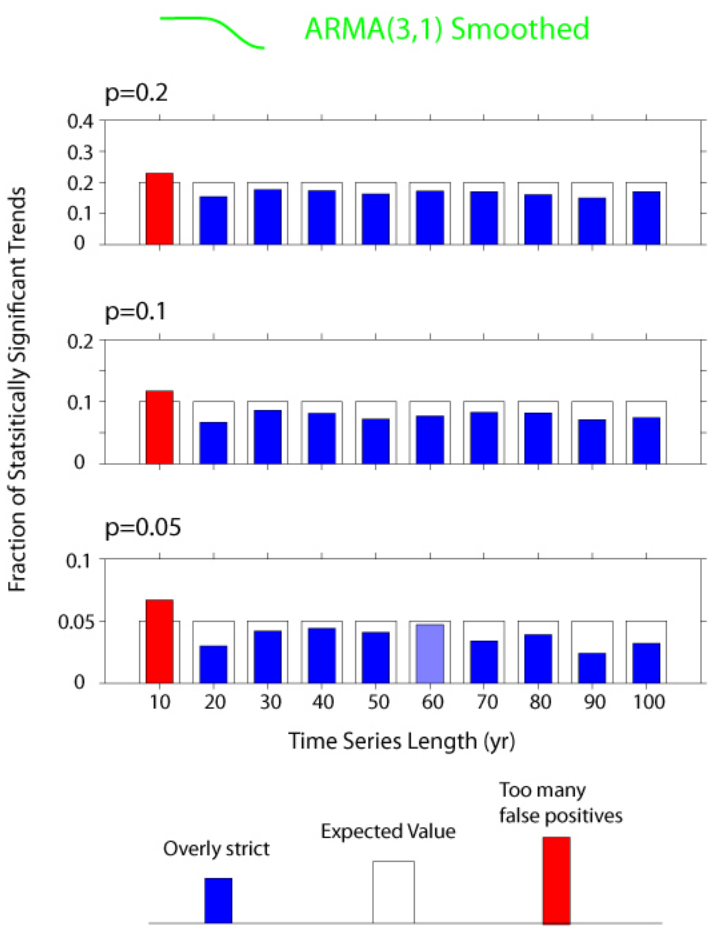




Monte Carlo Tests

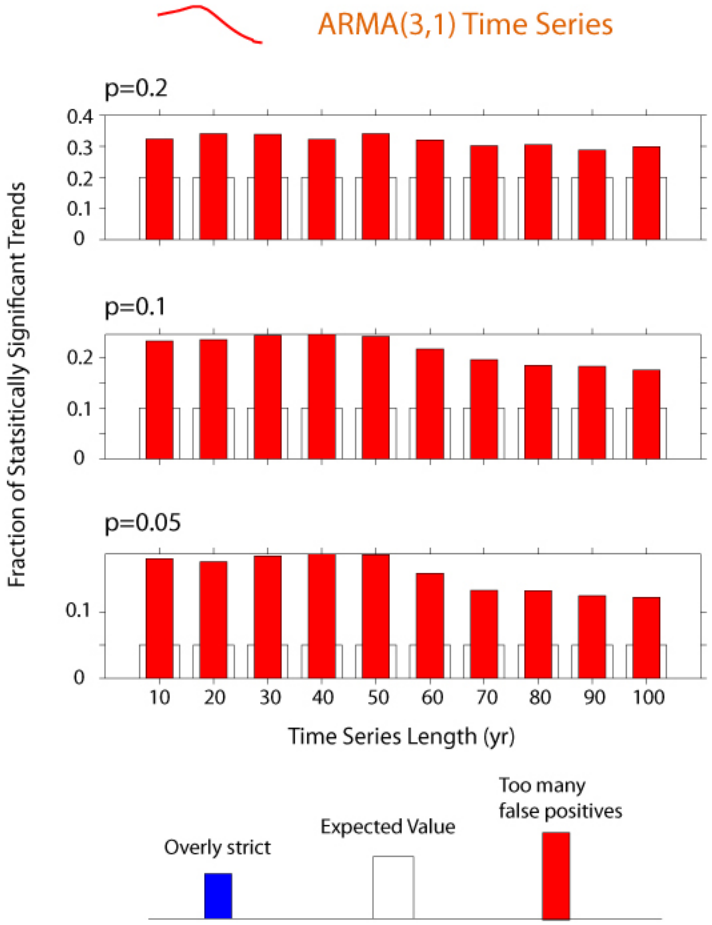
- Bootstrap tests (Results similar to t-test)

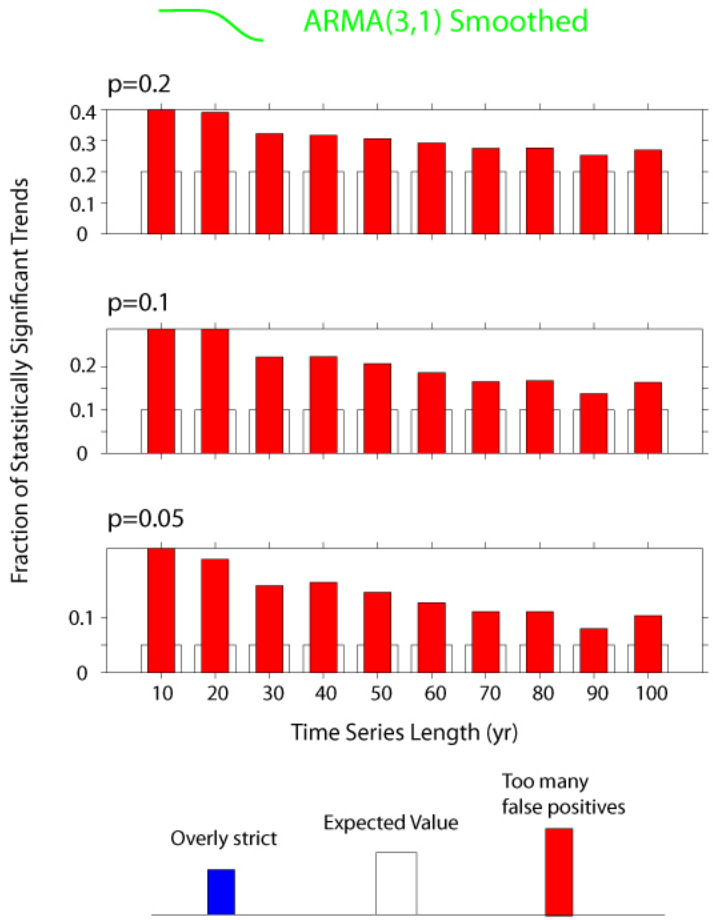




Monte Carlo Tests

- ARMA(3,1) Synthetic – Results are overly permissive





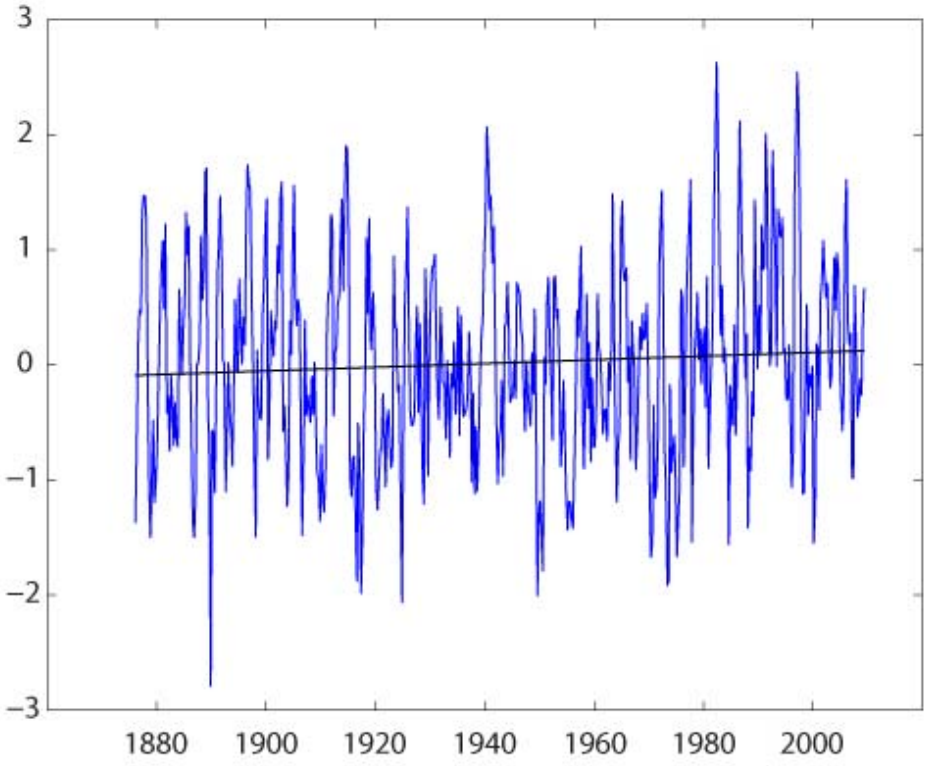
Monte Carlo Test Synopsis

- Using ARMA(3,1)-type tests appears to be unwise (too permissive)

- Even with a century-length record, uncertainties about the underlying distribution prevent us from knowing if Bootstrap and Student's t test will be accurate.

Darwin Results: No Long-term Trend

Small Best Fit Trend: 0.0004 mb/sea

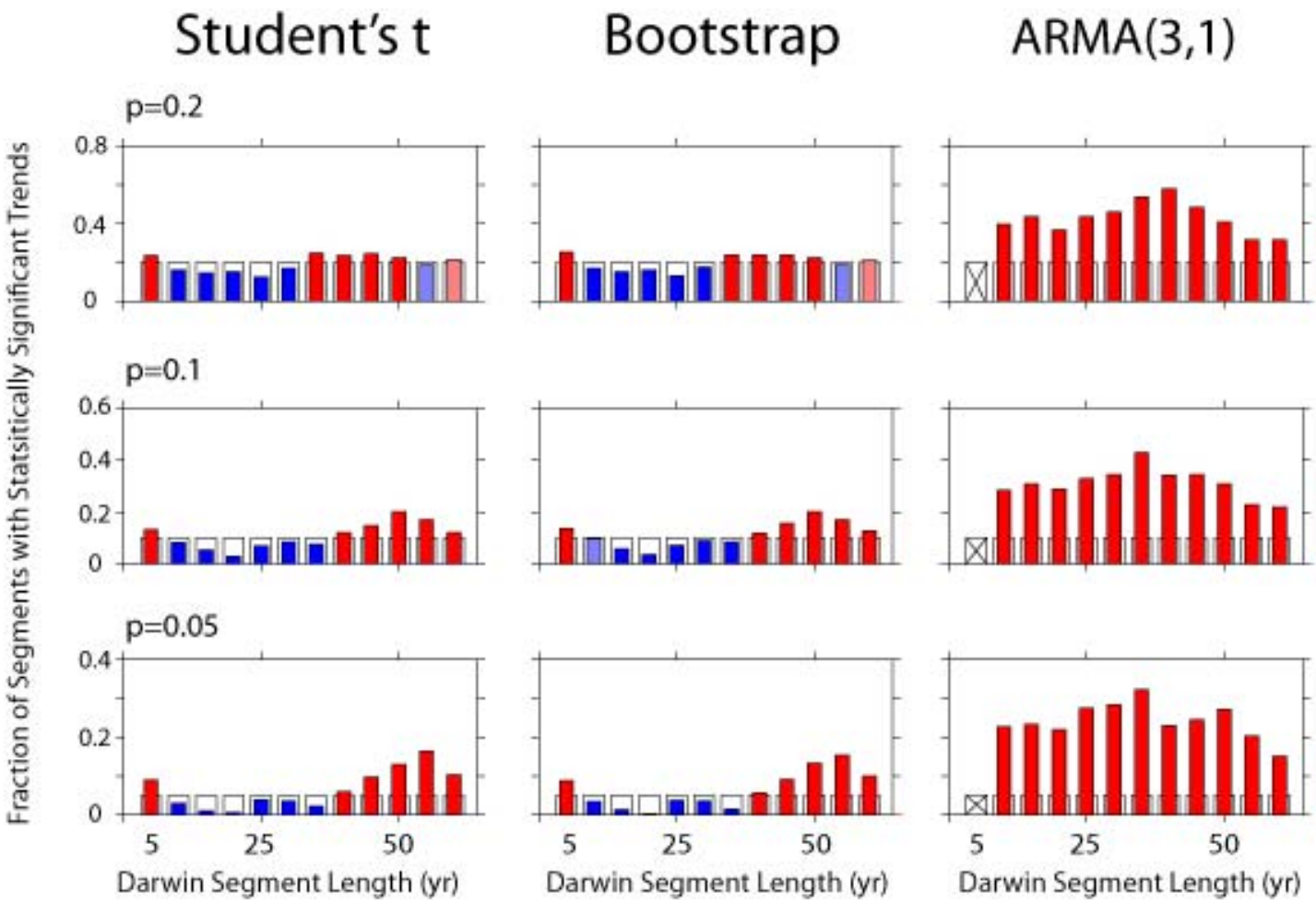


Trend Signficance is below 80%:

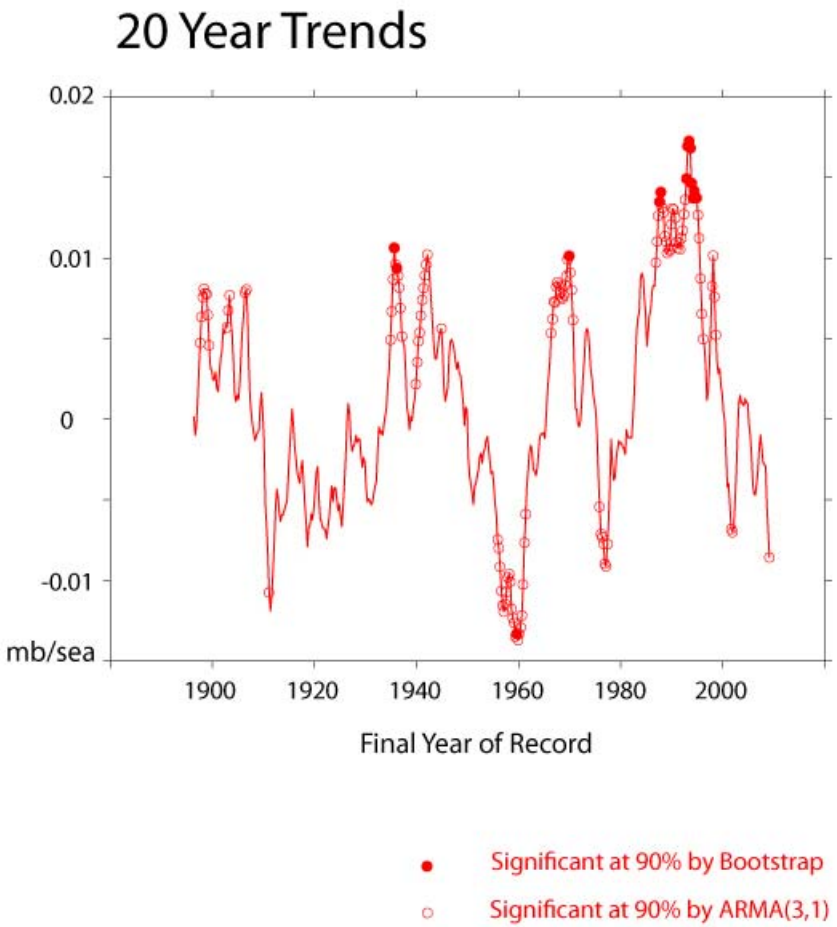
62% by Bootstrap

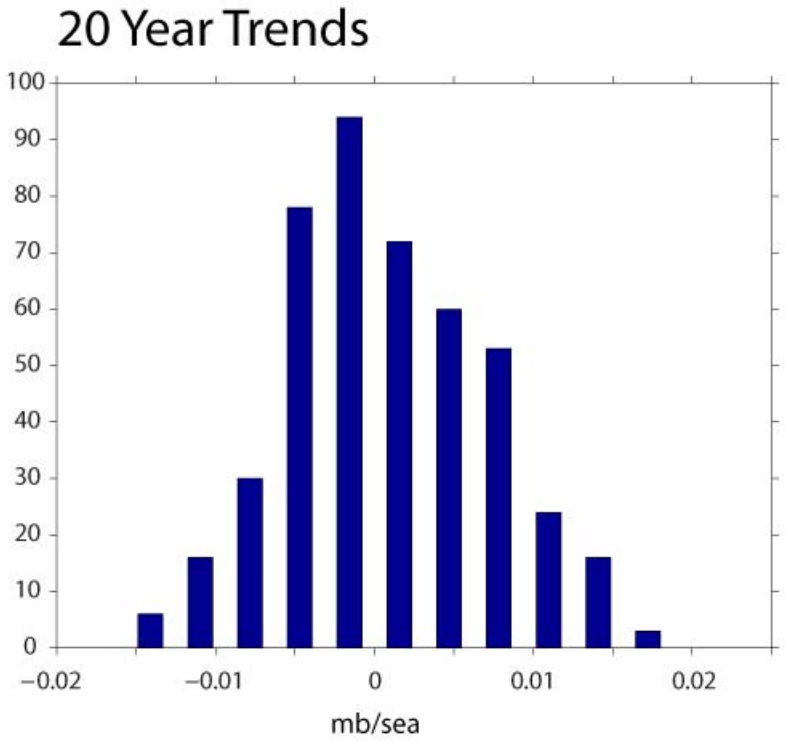
77% by ARMA(3,1)-Synthetic

Darwin Results: multi-decadal perspective

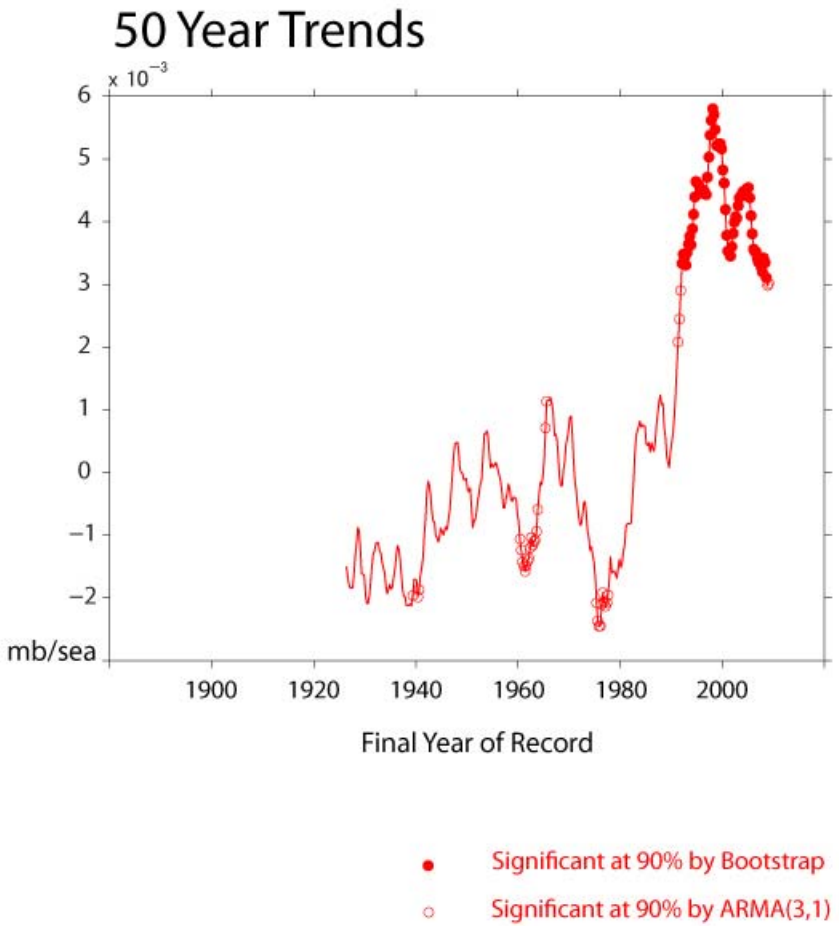


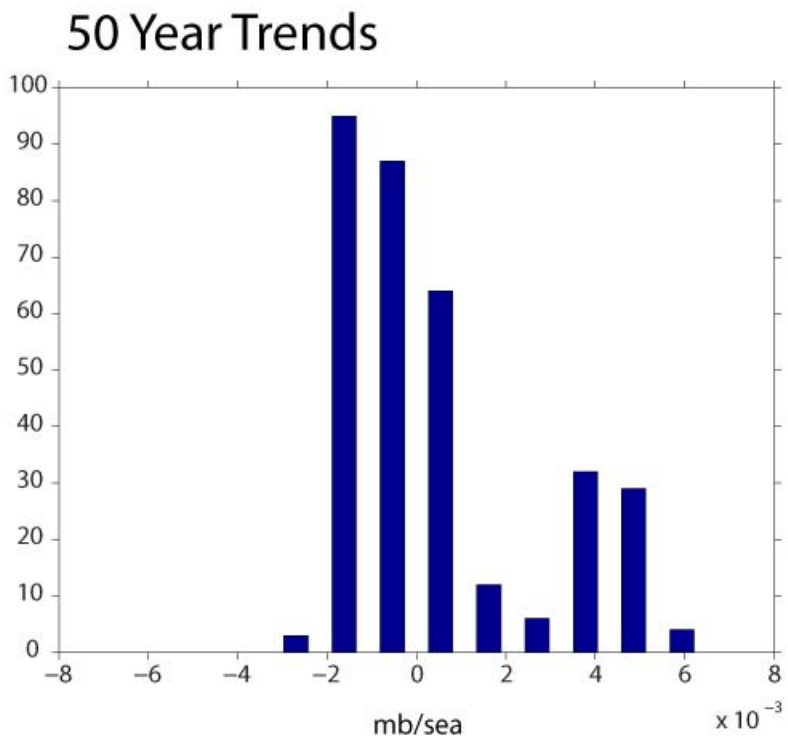
Darwin Results





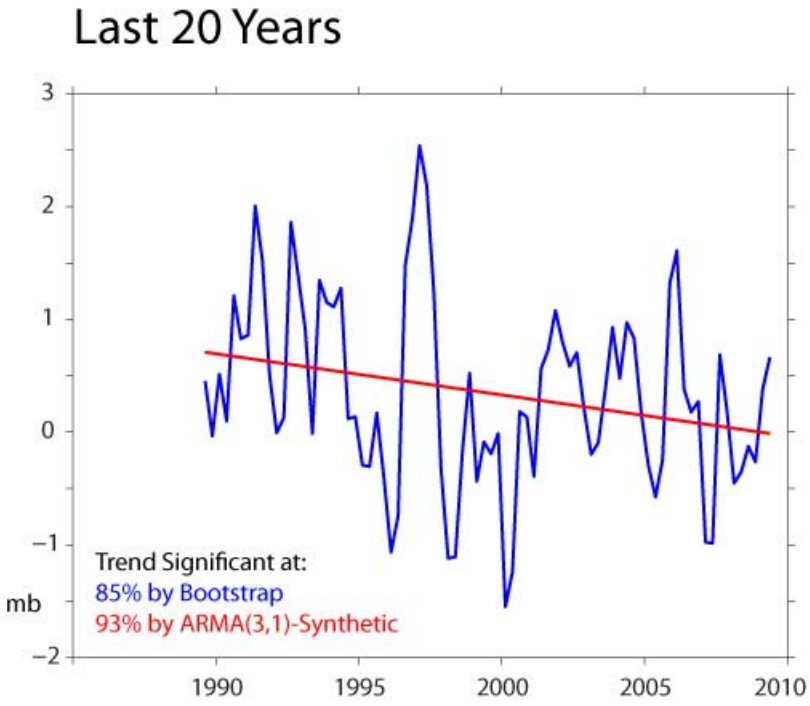
Darwin Results

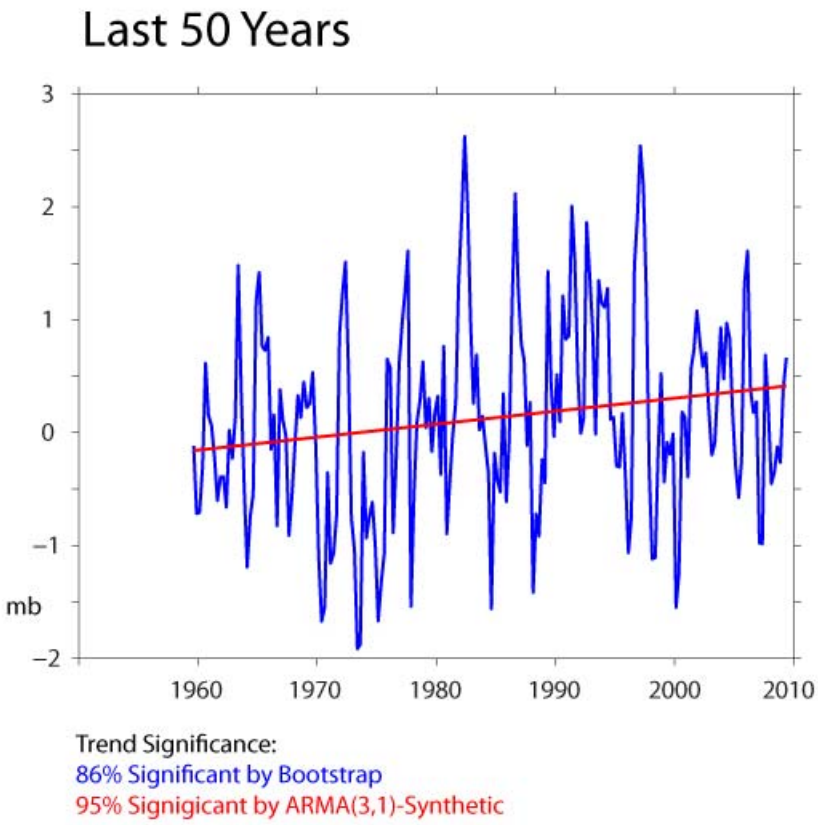




Results, again

Multi-decadal trends have intrinsic interest, but are not representative of longer term trends in Darwin.



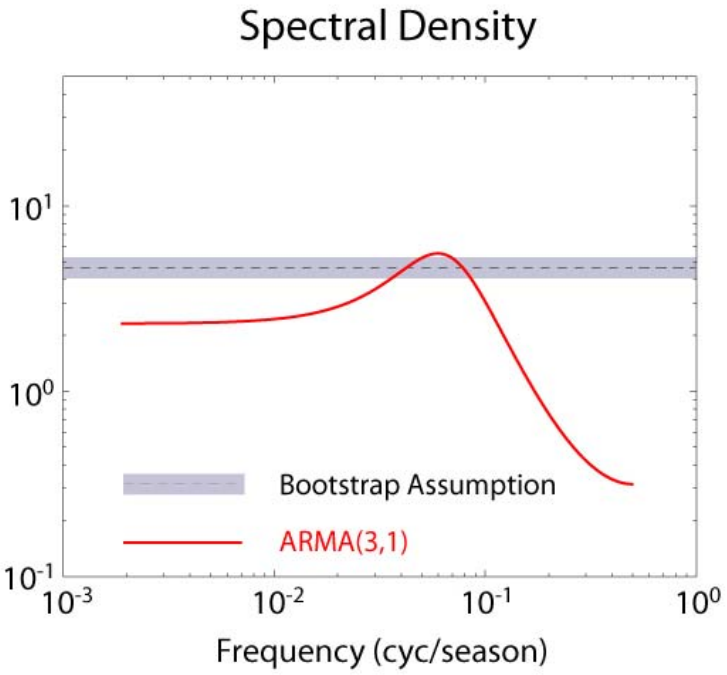


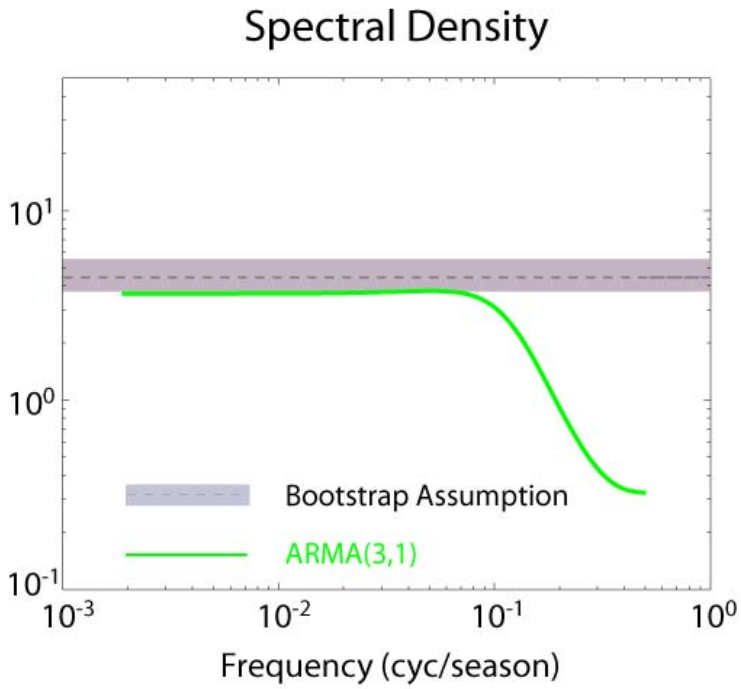
Conclusions

- No long-term trend in Darwin SLPA
- Rich variety of trends at multi-decadal timescales (positive/negative, significant/not)
- Multi-decadal segments not useful for determining very long term trends in Darwin. We suggest this is a feature of red-shifted geophysical time series.
- Determining trend statistical significance in red-shifted time series is difficult.

Monte Carlo Tests

- Bootstrap Assumed Spectra

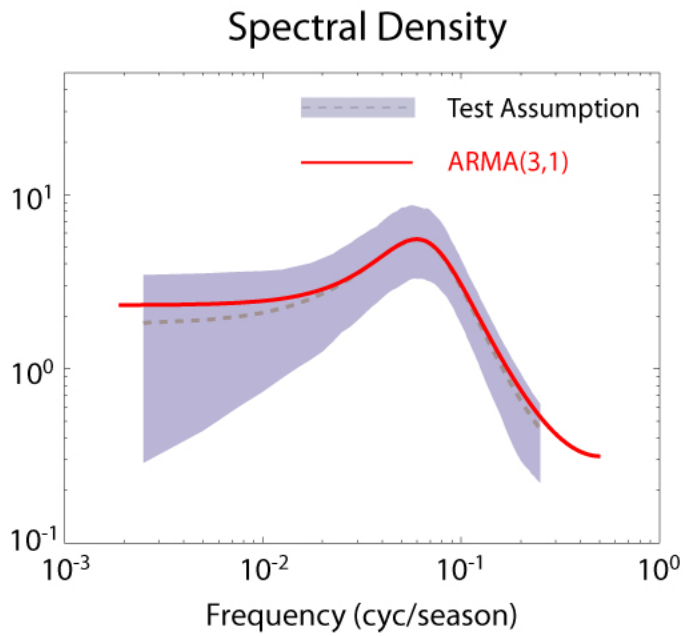


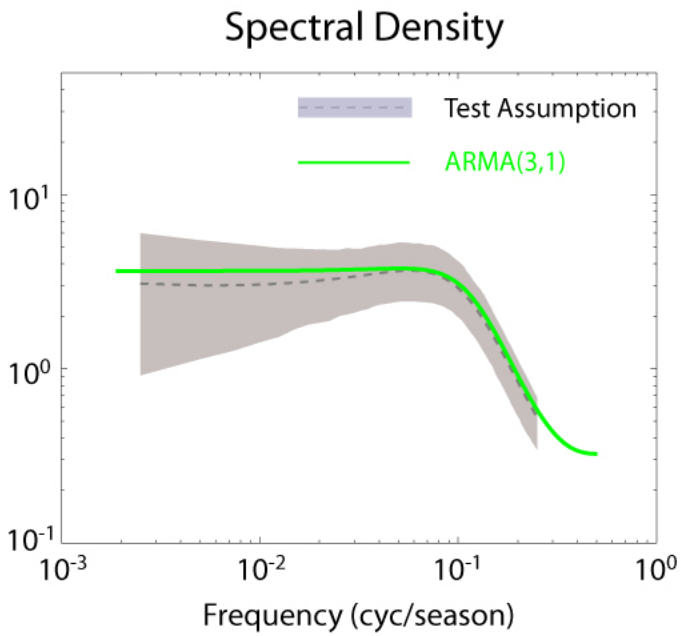


Test Period = 100 years

Monte Carlo Tests

- ARMA(3,1) Sample-fit Spectra



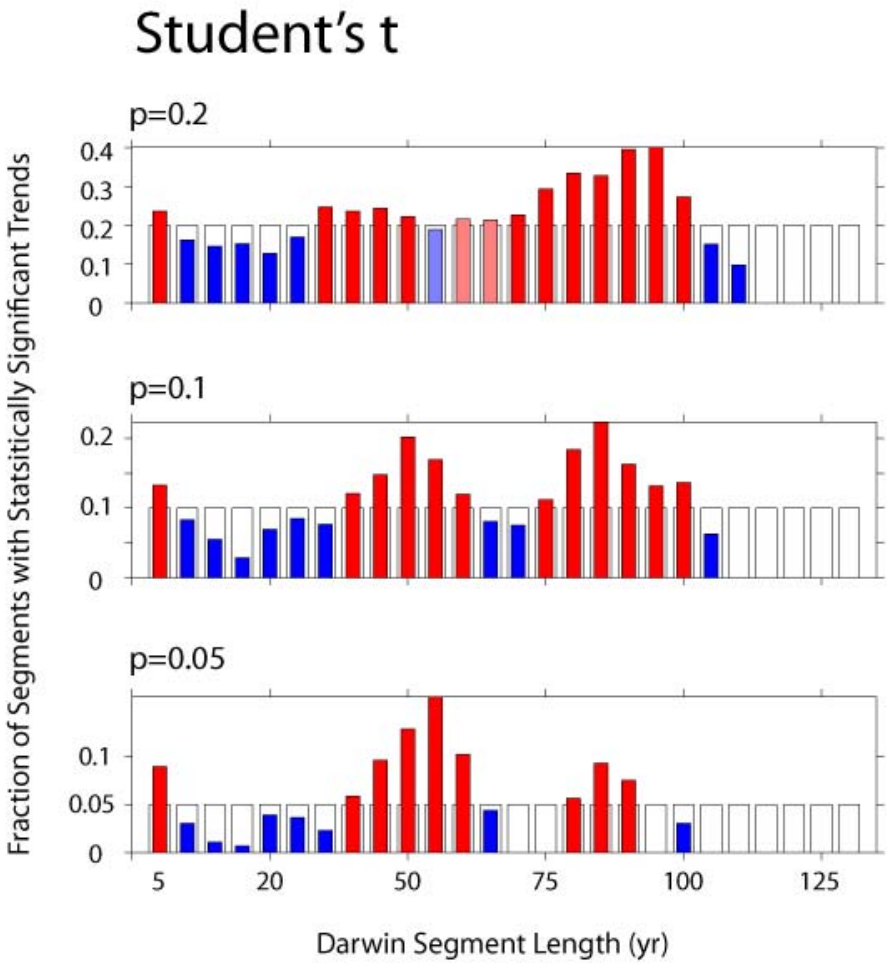


Test Period = 100 years

Darwin Results: multi-decadal perspective

Some statistically significant trends occur at each multi-decadal timescale.

For some segment-lengths, more trends are significant than expected.



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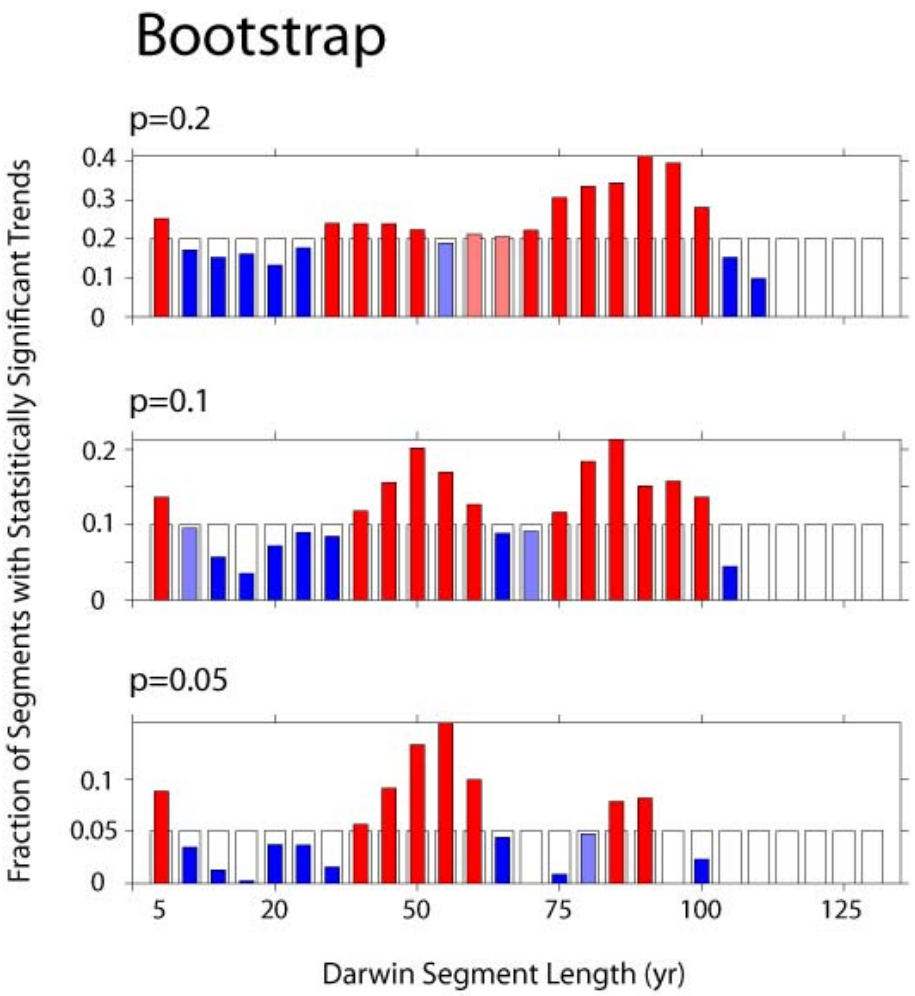

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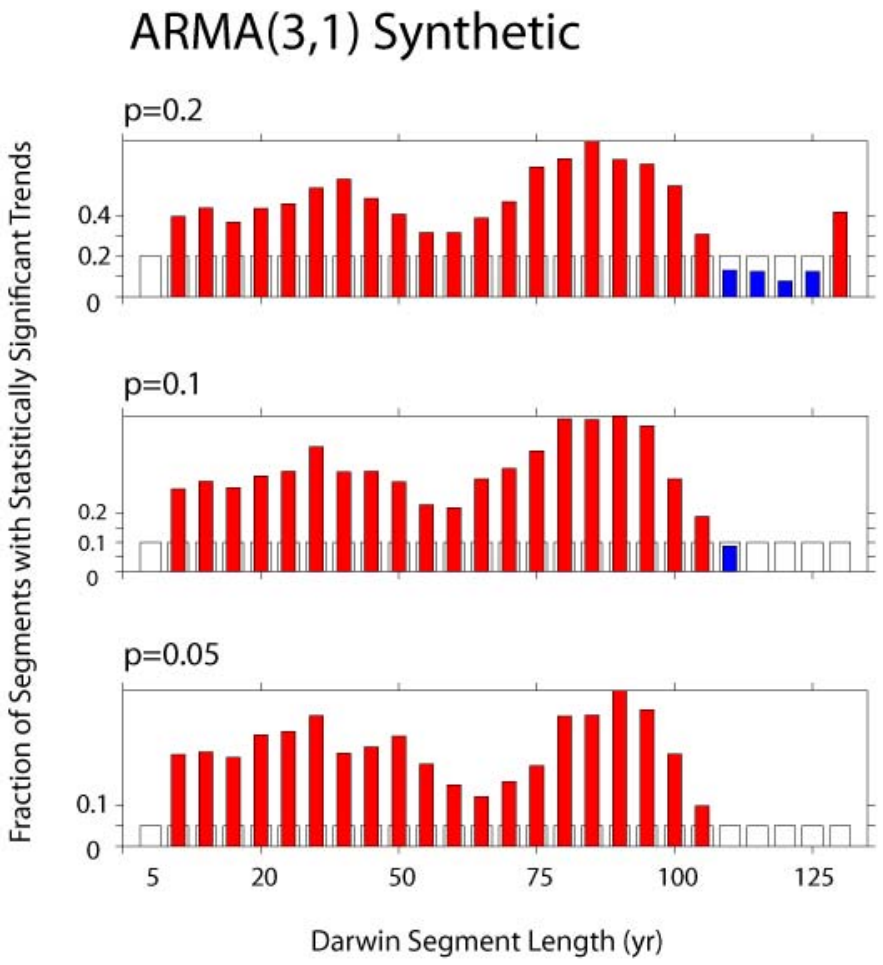
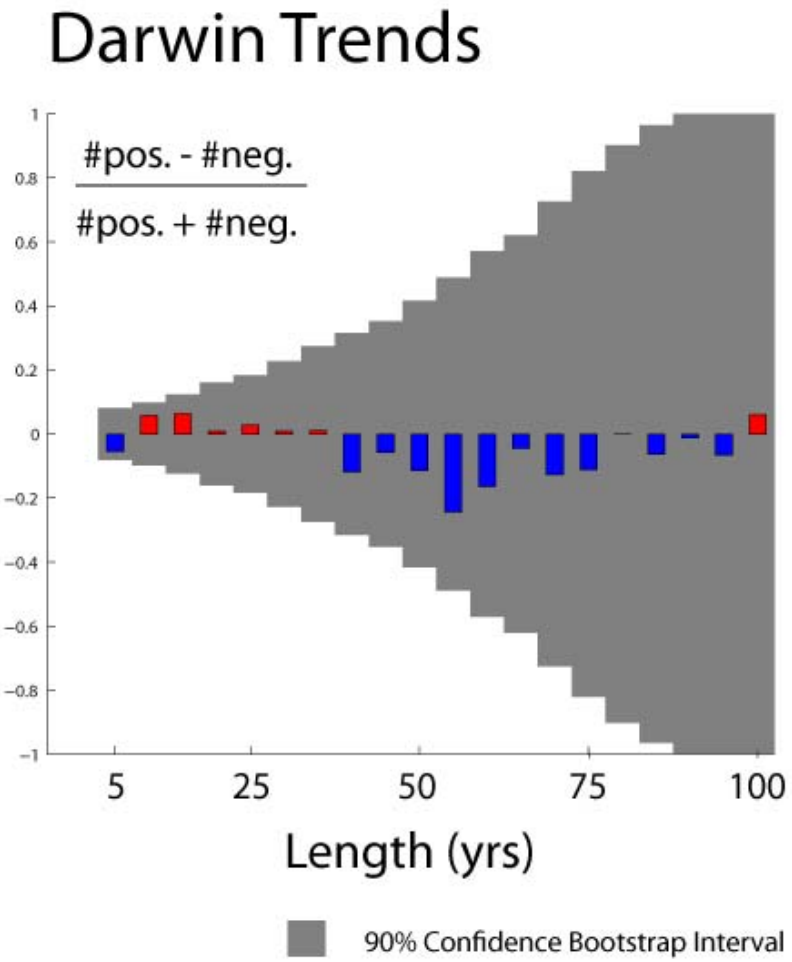


Darwin Results



- Relative numbers of positive and negative multi-decadal trends are balanced
- This is consistent with there being no long term trend

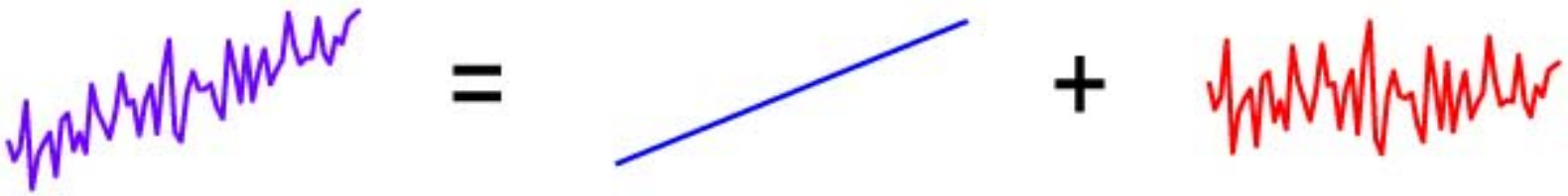
Trend Statistical Significance

In the simplest case, testing for trend significance depends on:

# of samples

slope

standard deviation of detrended series



Trend Statistical Significance

- Typical geophysical records are much more complicated

- Accurately estimating the amount of low frequency variance is key to a reliable test.

- For record-length trend estimation, this information is provided largely by assumption.