Australian Water School Python for Hydrogeology and Hydrology course

Session #2, 10 June 2021: Time series analysis

Materials for pre-reading, or for future reference

Hi folks, I'm looking forward to sharing some of my experiences with Python tools for time series analysis next week. As an initial disclaimer, all of my knowledge of these methods has come from their applied use, rather than from having studied them formally. For this reason, I won't present a comprehensive summary of all time series methods – instead I'll share some of the tools that I currently use to add value when interpreting time series data, beyond their traditional use in hydrograph and potentiometric surface analyses. In advance of session #2 next week, I have tried to find resources (mostly webpages) that demonstrate some of the concepts that I'll be covering, especially if they are foreign (or long forgotten!). In particular, I've tried to find visual explanations, as these are usually more intuitive than a page of equations.
– Chris Turnadge

1. Data wrangling

- **Detrending in the time domain:**
  https://towardsdatascience.com/moving-averages-in-python-16170e20f6c
  This webpage includes worked examples of detrending time series using moving average filtering. We'll be focusing on simple moving averages, but cumulative and exponential moving averages are covered too.

- **Detrending in the frequency domain:**
  https://pysdr.org/content/filters.html
  This webpage includes visual depictions of the various types of frequency domain filters, and a worked example of using a lowpass filter to remove unwanted frequencies in measured data.

2. Interpreting responses to time-lagged processes

- **Convolution:**
  https://lpsa.swarthmore.edu/Convolution/CI.html
  This webpage contains an interactive demonstration of the convolution of two functions. To make this relevant, I suggest using a "damped sine" for the h(t) function to crudely represent a measured time series. For the response function f(t), I suggest choosing one of the three exponential functions (i.e. Exp, Fast Exp, or Very Fast Exp), which are commonly used to characterise hydrological responses.

- **Deconvolution:**
  https://docs.scipy.org/doc/scipy/reference/optimize.html
  Deconvolution essentially involves fitting a convolution model to a measured time series. As we will be using Python's optimisation tools to perform this kind of model inversion, I just want to draw your attention to the broad range of optimisation algorithms available in the SciPy package, as listed on this webpage.

- **Example application:** Characterising time-lagged groundwater pressure responses to variations in barometric pressure
  http://www.hydrology.uga.edu/rasmussen/pubs/GW1997.pdf
  This publication demonstrates how groundwater responses (Figure 6) can be interpreted in terms of their responses to atmospheric pressure (Figure 5a), which are characterised by the response functions shown in Figure 9. The shapes of the three key response types are shown in Figure 2.

3. Interpreting responses to periodic processes

- **Decomposition of a time series into a sum of sinusoidal components:**
  https://jackschaedler.github.io/circles-sines-signals/dft_introduction.html
  This webpage describes how a measured signal can be decomposed into a sum of a limited number of sine waves. It includes an interactive demonstration at the bottom of the page, where the relative contributions of five components can be varied, and the effect on the summed signal is shown. More generally, this website is a great resource for visual explanations of concepts in signal analysis.

- **Methods of amplitude and phase spectra calculation:**
  https://blog.endaq.com/vibration-analysis-fft-psd-and-spectrogram
  This webpage provides visual examples of the types of methods and output plots that can be used to characterise responses to periodic processes. This includes an explanation of the difference between amplitude spectra and periodograms. Something we won't cover in detail are spectrograms, which are useful when interpreting responses to non-stationary periodic processes.

- **Example application:** Characterising groundwater pressure responses to periodic variations in Earth tide strain
  https://raw.githubusercontent.com/AustralianWaterSchool/PythonForHydrologyAndHydrogeology/main/Session2/Turnadge%20et%20al.%20(2019).pdf
  This paper provides an example of how groundwater pressure responses (Figure 2) to Earth tides (Figure 3a) were used to estimate confinement status and specific storage values for various aquifers in the Peel region of Western Australia.