**Obspy Code for Calculating the Transverse acceleration ,Rotation rates, their spectrograms and correlation coefficients**

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**Acquiring Instrument Data**

A seismic station is always a part of network of seismic stations, therefore associated with each seismic station is the Station and Network code. Network code determines the operator of a particular group of seismic stations. The station code identifies the particular site hosting the instruments. Most stations include more than one sensor at different sites/elevations and are identified by location codes. Channel codes identify the orientation of sensors.

First we will import the necessary python packages such as Obspy, Numpy, Scipy and Matplotlib.

**Inputs**

The users will first provide earthquake name which should be descriptive for example “Nepal 5.3 2020-09-15 23:11:47” (in this format only), followed by earthquake depth (just for information), followed by Latitudes and Longitudes of epicenter of earthquake. The latitudes and longitudes should be in the float value format, Latitudes will vary from -90 to 90 and Longitudes from -180 to 180; Negative values for south and west of equator.

**Objective of Code**

The code demonstrates the concept by Heiner Igel (2007) “transversal acceleration and rotation rate should have the same waveform and their amplitudes should scale proportionally to phase velocity depending on wave type” (Igel *et al*., 2007). Thus the user is able to correlate the two time series he is interested in by just looking at them.

**Background**

Inertial seismometers measure three components of translational ground displacement and form the basis for any interpretation of seismic events.

In the past years, ring laser gyroscopes were developed that close the missing gap in order to fully describe the complete motion of a seismic wave propagating through the earth. (Igel *et al*., 2005, 2007) By feeding datacenters with those new ground rotation rates as a fourth component for two seismic stations in the world (Christchurch, New Zealand and Wettzell, Germany), seismologists are able to complement the recent seismic models of the earth. Thus, in April 2010 seismologists could observe rotational motions from the Earth’s free oscillations (Kurrle *et al*., 2010). Furthermore, there were several articles in geophysical related journals that pick out rotational motions as a central theme. A group of seismologists established an international working group on rotational seismology in 2007 that made an issue out of the new measurement technique by ring laser technology.

To obtain the corresponding time-window for a specific earthquake, we need to know the latitude, longitude and depth of the event source and the longitude and latitude of the seismic station recording the seismic event. There are a number of formulae that are able to calculate accurate azimuths and distances on the WGS84 ellipsoid. One formula that works with an accuracy of a few millimeters, ranging within a distance of a few cm to 20.000km, is the Vincenty’s formulae. As we want to know the distance from the event source to our seismic station we are confronted with an inverse problem. The formula to calculate the epicentral distance *s* from source to station is given by s = bA(ϭ-Δϭ)

where *b* is the length of the minor axis of the ellipsoid and the angular distance on the sphere. (Wikipedia, 2010) There are several models to calculate the ray path for a specific phase velocity. But we only need the arrival times of the corresponding phases, especially the last phase to obtain the parameter for the time-window. To derive it, we just need to divide the phase velocity by the distance.

Modern seismographs like the STS-2 Streckheisen seismometer located at Wettzell, Germany, are designed to achieve a linear response to Earth motions over a wide frequency band. It is desirable to have an instrument as sensitive to be able to record below typical Earth noise levels and at the same time be able to record large earthquakes. To obtain such results modern seismograms use force-feedback designs in which the mass is maintained at a fixed point. Thus the measurement is not done by measuring the amplitude of the mass due to seismic activity but the force that is required to keep the mass at the fixed point.

Consequently the STS-2 uses three identical mechanical sensors to measure the horizontal and vertical components of a seismic event. Furthermore the output proportional to veloci-ty is not filtered and the feedback system delivers it directly from the feedback loop. The response from the seismometer is defined by a corner frequency from 8.33 mHz up to 50 Hz. (STS-2 Manual, 1995) The instrument’s response can be defined in terms of the relationship between digital counts in the recorded time series and the actual ground motion of the Earth. The gain of an instrument is the ratio between the digital counts and the measurement of the ground motion. All information specifically oriented and calibrated sensors are described by the complete instrument’s response function which is embedded in the seismic record that can be downloaded from datacenters.

Obspy now have build-in function such as remove\_response that can remove the instrument response and output in the form of displacement/velocity/acceleration.

For the G-ring no instrument correction is necessary because of the uniform transfer function of optical sensors due to a mass-less recording system. The raw data is converted and scaled correctly to compare with the seismometer’s data.

**Rotation of horizontal components**

To rotate the North- and East-Component of a seismogram to Radial and Transversal com-ponents, we need to calculate the back-azimuth. The back-azimuth is the angle measured between the vector pointing from the station to the source and the vector pointing from the station to geographic north.

**Estimation of spectra**

To identify periodicities in the seismic data and estimate e.g. the Earth’s normal modes, we need to calculate the logarithmic spectrum of the transversal and rotational component. This is done by filtering the record by removing all energy near and above the Nyquist frequency first and then using a sampling interval so that the Nyquist frequency lies above the highest frequency in the original data. Then the data gets split into NFFT (Nonequi-distans Fast Fourier Transform) length segments, and computed for the power spectral density (PSD) by Welch’s average periodogram method (Welch, 1967). Each segment is then detrended by removing a best fit line and windowed by x times with the hanning window of the time sequence. So the sequence is tapered to smooth the ends of the time series to zero which reduces spectral leakage but broadens central peaks. The last step pads the time series with zeros to make the number of samples a power of 2 for the FFT (Fast Fourier Transform). This also smooths the spectrum by interpolation while not increasing the actual resolution, but giving more points in the corresponding plot. (Bendat *et al*., 1986; Shearer, 2009; Gubbins, 2008)

The correlation coefficient for the whole seismogram is equal to the cross correlation normalized function. It returns the value 1 if two sequences are perfectly correlated and identical.

If it is 1 there is a perfect correlation of two seismic sequences, but in general it is considered as less than 1 for seismic data (Shearer, 2009)

The formula for empiric correlation coefficient used for computing the sliding time window is given in Wikipedia, and it comes out to be 30s, With this formula (Wikipedia, 2010) we calculate the correlation of all 600 samples (30s) and plot the highest correlation value of each window. The resulting function is then plotted underneath the superposition of the transversal acceleration and rotation rate to provide a good overview.

**Obspy Routines**

To receive a quick overview of all data downloaded from the servers, the first plot provides the user with an unaffected display of the four different seismic streams. Here the user could pre-check if the download of the data went right. Towards the following display of the data, the time axis is presented with original UTC time here and the amplitude axis is given in integer values directly received from the stored sensor data.

Then the program will calculate the backarc angle for rotation of components. Backarc angle is the angle the line joining from station to event makes with respect to the North direction and is measure in the clockwise way from North. Forearc is the angle between the line joining event to station makes with the North direction, It has 180 degrees of lag from the station.

Obspy function gps2\_dist calculates distance(in metres), backarc and forearc.

More information is available [here](https://service.iris.edu/irisws/rotation/docs/1/help/)

One of the main guidelines and ideas behind this program was the consideration of the transversal acceleration and the rotation rate measured by the Ringlaser. To obtain the transversal acceleration we rotate the horizontal seismometer components and then differentiate the result.

Due to the fact that this step is one of the most important ones the script provides three plots for it. One plot displays both time series separately, the second one is a superposition plot of the two signals and the third one is a superposition plot with a sliding time window directly underneath the superposition to show the correlation coefficient and their coherence (Figure 14). The numerous peaks in the maximum cross-correlation coefficient are an evidence for a good correlation of both time series.

The motivation behind the program is to develop a program that enables the seismologist to easily obtain a first over-view of translational and rotational ground displacements induced by earthquakes (velocity, acceleration, rotation rate). With the tool developed in this program, a seismologist who is interested in transversal and rotational similarity can easily get a first overview of the earthquake he is interested in.

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