Introduction to Earthquake Seismology
Assignment 6

Department of Earth and Atmospheric Sciences **EASA-462**
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Regional Distances

Goals:

- Determine epicentral distance, azimuth and back-azimuth between 2 points on the Earth's surface using a short distance, flat-Earth approximation.
- Determine the distances for some coordinate sets which will later be compared to values computed using spherical-Earth equations.

Background:

Three coordinates define the location of an earthquake - latitude, its north-south position, longitude, its east-west position, and depth. Similarly, the location of a seismograph station is given by latitude, longitude and elevation (note that positive elevation and depth indicate the distance above and below sea level, respectively).

To study seismic velocities within the Earth and to locate earthquakes, we must be able to compute the distance between the earthquake and station, epicentral distance given either has degrees or kilometers along the surface, the azimuth from the the earthquake to the station and the back azimuth from the station to the earthquake. These computations are performed using spherical trigonometry, which will be the subject of Assignments 7 and 8.

However, when the seismograph station is located near the earthquake, we can consider the Earth as flat, and then apply plane geometry and plane trigonometry.

Figure 1 indicates the nature of the problem to be addressed as well as the approximation that we will apply. we are interested in the epicentral distance, the azimuth and back azimuth. To do this, we define Δx and Δy as the difference in N-S and E-W distances in kilometers, respectively, between the epicenter and the station:

$$\Delta x = 111.195\,(km/deg)\,(\phi_s - \phi_e)$$

$$\Delta y = 111.195\,(km/deg)\,(\lambda_s - \lambda_e)\cos\frac{\phi_e + \phi_s}{2}$$

where the coordinate angles are given in degrees. As you see we place the Cartesian grid at the latitude halfway between the station and the epicenter. The number 111.195 arises from using a mean Earth radius of 6371 km.

The desired epicentral distance, Δ, in km and *Az*, azimuth, and *Baz*, back-azimuth angles (°), are given by

$$\Delta = \sqrt{\Delta x^2 + \Delta y^2}$$

$$Az = \tan^{-1}(\Delta y/\Delta x)$$

$$Baz = \tan^{-1}(\Delta y/\Delta x) + 180$$

Note: When you compute the inverse tangent functions on a computer, you must be careful that you understand what is returned. The FORTRAN and C *atan2* and the EXCEL *ATANF* functions return the angle in radians (2π radians = 360°). In addition these functions are invoked as *atan2(y,x)* for FORTRAN and C, and *ATAN2(x;y)* in EXCEL and OpenOffice. To ensure that you understand the conversion, try some simple known angles. For a 30° angle and a radius of 1.0, $x = 0.866$ and $y = 0.5$. An spreadsheet formula that returns the correct number is

=ATAN2(0.866;0.5)*180/3.1415927 $\rightarrow$ 30

For the angle 225°, $x = -0.707$ and $y = -0.707$, and the formula

=ATAN2(-0.707;-0.707)*180/3.1415927 $\rightarrow$ -135

which is the same as 225° because of the then differ by 360°.

This experimental exercise using simple know facts about trigonometry helps when you are not familiar with the specifics of a math function. Since the spreadsheets use *radians*, you must compute the *cos* required by using the following operation if the angles are given in degrees

$$cos(0.5 * (\phi_e + \phi_2) * 3.1415927/180)$$

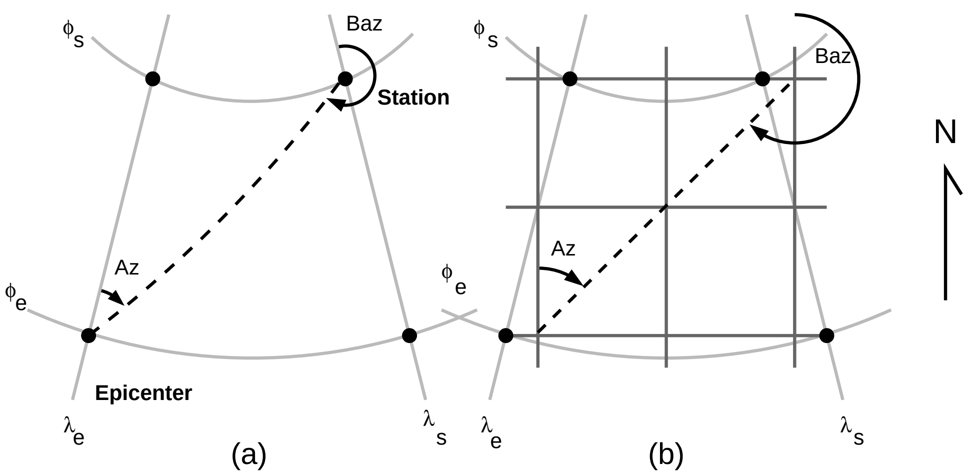

Fig. 1. The latitude and longitude coordinate pairs of the epicenter and station are (ϕ_e, λ_e) and (ϕ_s, λ_s), respectively. The location of the epicenter and station in spherical coordinates in represented in (a). (b) shows the placement of a rectangular grid the problem. In general the grid affects the distance and angles.

What you must do:

Because we wish to understand how the shape of the Earth affects computed distances, and because we wish to understand the limitations in the approximate formulas, the epicenter and station coordinates will focus on three different latitudes.

Determine the epicentral distance, azimuth from epicenter to station, and back azimuth for the following epicenter and station coordinates:

Low Latitudes

$\phi_e = 0 \quad \lambda_e = 0 \quad \phi_s = 1 \quad \lambda_s = 1 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

$\phi_e = 0 \quad \lambda_e = 0 \quad \phi_s = 5 \quad \lambda_s = 5 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

$\phi_e = 0 \quad \lambda_e = 0 \quad \phi_s = 10 \quad \lambda_s = 10 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

$\phi_e = 0 \quad \lambda_e = -30 \quad \phi_s = 60 \quad \lambda_s = 60 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

Mid Latitudes

$\phi_e = 40 \quad \lambda_e = 0 \quad \phi_s = 41 \quad \lambda_s = 1 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

$\phi_e = 40 \quad \lambda_e = 0 \quad \phi_s = 45 \quad \lambda_s = 5 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

$\phi_e = 40 \quad \lambda_e = 0 \quad \phi_s = 50 \quad \lambda_s = 10 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

High Latitudes

$\phi_e = 60 \quad \lambda_e = 0 \quad \phi_s = 61 \quad \lambda_s = 1 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

$\phi_e = 60 \quad \lambda_e = 0 \quad \phi_s = 65 \quad \lambda_s = 5 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

$\phi_e = 60 \quad \lambda_e = 0 \quad \phi_s = 70 \quad \lambda_s = 10 \quad Dist(km) = \_\_\_\_\_ \quad Az(deg) = \_\_\_\_\_ \quad Baz(deg) = \_\_\_\_\_$

What you must submit:

We only require the blanks to be filled in above.

Also submit an EXCEL file that asks you to enter the epicenter and station coordinates and which then computes the results.