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UBC

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Contents

Preface

This is the very first part of the book, which will eventually include the textbook's introduction. For now, here's some useful info for you:

0.1 Contacts

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0.2 Project Wiki

github.com/ubc-geomatics-textbook/docs/wiki

0.3 Style Guide

0.3.1 Audience

1. Audience is undergraduate of graduate student studying GIS, geomatics, and remote sensing with no prior knowledge in these subject areas (i.e., introductory).
2. Assume only first year-level knowledge (or equivalent concurrent learning) of mathematics, science (biology, chemistry, physics), and geography.
3. Assume a multicultural reader who is not necessarily familiar with Canadian geography and history.

0.3.2 General Style

1. Word spellings should follow *The Oxford Canadian Dictionary (2 ed.)*.
2. Every chapter begins with 1-3 paragraphs of introductory text. The introductory text should be for general interest and not introduce any important terms that will be defined later in the chapter. The last sentence of this introductory text should summarize what students will learn.

3. Posing questions to readers is encouraged in all sections. For example, “Have you ever wondered…?” “How do you think X relates to Y?”
4. At every opportunity, authors should highlight Canadian examples of technology and science in geomatics. Examples of geomatics applications are highly encouraged in the Canadian context. For example, the following list of environmental management problems that are important to Canada should be discussed whenever possible:
   - Northern communities
   - First Nations
   - Climate change
   - Boreal forest
   - Endangered wildlife
   - Freshwater management and ecosystems
   - Fisheries
   - Glaciers/ice monitoring
   - Environmental justice
   - Resource extraction

0.3.3 Learning Objectives

1. Every chapter will have a numbered list of learning objectives that follow the introductory text.
2. There should be no period at the end of each listed learning objective.

0.3.4 Summary

1. All learning objectives should be addressed in the summary section.
2. The summary section should never introduce any new concepts, terms, or definitions and should never reference figures, tables, or equations.

0.3.5 Key Terms

1. Every chapter will have an alphabetical, but unnumbered list of key terms.
2. At first mention in the chapter text, key terms should be boldened and defined.

0.3.6 Headings and Labels

1. Chapter titles should use title-case and are numbered.
2. Chapter sub-titles are also numbered and in title-case. Sub-titles should go no lower than level 3 heading (i.e., 1.2.3).
3. Level 4 headings are not numbered, all letters are capitalized, and should only be used in special call-out boxes:
   - LEARNING OBJECTIVES
   - REMEMBER THIS?
   - YOUR TURN!

- CASE STUDY

0.3.7 Formulae

1. Do not format formulae using Microsoft Word or LaTeX. Instead, formulae should be formatted with RMarkdown.
2. Coordinates and Greek letters should always be formatted as formulae with RMarkdown.

0.3.8 Units

1. Standard International (SI) units should be used for the following:
   - Length = meter (m)
   - Time = second (s)
   - Amount of substance = mole (mole)
   - Electric current = ampere (A)
   - Temperature = Kelvin (K)
   - Luminous intensity = candela (cd)
   - Mass = Kilogram (kg)
2. Angle degrees are preferred over radians (rad) when referencing geographic position.
3. Rates should be expressed with a dot operator and negative exponent rather than a divisor (e.g., m · s-1 or W · m-2).

0.3.9 Numbers

1. Scientific notation is the preferred way to represent large and small numbers and should use the × operator (not dot or asterisk) and be formatted as a formula (see Formulae): 1 × 102.
2. Scientific notation should be limited to four significant figures (e.g., 1.234 × 100) except for specific numbers where the precision is important or meaningful like the speed of light (2.99792458 × 108 m · s-1) or Planck's constant (6.62607004 × 10-34 J · s-1).
3. Constants (like above) and other physical variables should use common notations (e.g., c for speed of light and h for Planck's constant) and be formatted as formulae (see Formulae).

0.3.10 Dates and Times

1. The Gregorian calendar should be adopted for recent dates. In these cases, use Common Era (C.E.) to indicate dates after 0 A.D. and Before Common Era (B.C.E.) for dates before 0 A.D.
   - For specific recent dates, use the format "20 February 2021" and omit C.E.
   - If many dates need to be summarized in a table, use the format "DD-MM-YYYY"

2. Times should be specified in either Local Standard Time (LST) or Coordinated Universal Time (UTC) using a 24-hour clock:
    - 00:00 = 12 A.M. midnight LST
    - 12:00 = 12 P.M. noon LST
    - 23:00 = 11 P.M. LST
3. For non-recent dates or when referring to geologic time scales, use the following:
    - Thousands of years before present = kilo annum (ka)
    - Millions of years before present = mega annum (Ma)
    - Billions of years = giga annum (Ga)

0.3.11 Tables

1. Tables are numbered in the order that they appear in text and begin with the number of the chapter:
    - Table 1 in Chapter 1 = 1.1
2. A short, descriptive caption should be written for a table.
3. Tables should only include information that is discussed or referenced in the chapter text.
4. Every table must be referenced in the chapter text.

0.3.12 Code Blocks

1. Avoid code blocks in chapter text. Instead, try to place code blocks in TRY THIS! or CASE STUDY sections.
2. Only R code blocks should be embedded using RMarkdown.

0.3.13 Abbreviations

1. Abbreviations are shortened form of a word or phrase and should be punctuated with periods:
    - e.g.
    - Dr.
    - Ph.D.

0.3.14 Initialisms

1. Initialisms are the first letters of several words and should always be defined at first use in the chapter text regardless if the initialism is introduced and defined in an earlier chapter.
2. Do not introduce initialisms in figure or table captions or table text.
3. Except for the specific cases in this style guide, do not punctuate initialisms with periods:
    - AVHRR
    - NDVI

0.3.15 Acronyms

1. Acronyms are combinations of the first letters of several words and are pronounced as words. Acronyms should never be punctuated with periods.
2. Many satellites and remote sensing systems have acronyms that vary capitalization.
3. Following are some preferred acronyms:
   - Light Detection and Ranging = LiDAR
   - Radio Detection and Ranging = RADAR
   - Moderate Resolution Imaging Spectroradiometer = MODIS

0.3.16 Punctuation

1. Use serial comma (Oxford comma) in lists: Yukon, Northwest Territories, and Nunavut.
2. Use italics for internal dialogue or when you infer what the reader might be thinking:
   - "At this point, you might be wondering, *why am I reading this sentence?*"
3. Avoid the use of semi-colons.
4. Use and punctuate common Latin abbreviations with periods:
   - "For example" = exempli gratia (e.g.)
   - "That is" = is est (i.e.)
   - "And other similar things" = et cetera (etc.)
5. Avoid phrases in parentheses () or brackets []. Instead, place the phrase in a proper sentence.
6. Use single spaces between sentences.
7. Use double quotation marks for direct quotes, but avoid reproducing verbatim large texts. Paraphrasing with proper citation is preferred to direct quotation.
8. Bullet points are preferred over long lists in sentences.

0.3.17 Citations

1. Style should follow American Psychological Association (APA) format.
2. In-text references are encouraged where necessary, especially in case studies.
3. References and Recommended Readings section is placed at end of each chapter. Where possible, Recommended Readings should be populated with Open Educational Resources.

Chapter 1

What is Geomatics?

We encounter and use geographic information on a regular basis in our everyday lives. Whether it is finding directions to a retailer that has an item in stock you want to buy or recording the path of your last morning jog, you have probably used a Geographic Information System (GIS) and not even realized it.

:::: {.box-content .learning-objectives-content}

::: {.box-title .learning-objectives-top} ## Learning Objectives {-} ::: 1. ::::

Key Terms {-}

Geomatics, Geographic Information Systems, Remote Sensing

1.1 The Science and Technology of Geomatics

Geomatics is the science and technology of collecting geographic data and converting it to geographic information for use in a wide variety of industries. As a technical field, it encompasses many different work processes including surveying, remote sensing, global navigation satellite systems, geospatial analysis, and information technology and systems management. In turn, these processes support a wide variety of spatial decision-making such as urban planning, ecological conservation, forest management, real-time planetary systems monitoring, and rapid response to natural disasters. Many more emerging technologies such as self-driving vehicles, ride-sharing apps, and augmented reality video games depend directly on the science and technology of geomatics.

1.2 A Brief History of Geomatics in Canada

remote sensing is any method of gathering information about an object, or objects, without physical contact.

1.3 Information Systems

An **information system** is used to store, code, and recall information. In the Information Age, we are surrounded and depend heavily on information systems such as financial systems that record the transactions in your bank account or navigation systems that tell you the fastest route to a destination or autonomous vehicles such as the SkyTrain rapid transit network in Vancouver, Canada that moves more than a half million people every day across the Metro Vancouver region. These are all examples of systems that require high synchronization and integration of many varied sources of information in order to move people and assets around. It should come as no surprise then that information systems and information technology contribute significantly to nearly every sector of developed and developing economies.

What makes a **Geographic Information System** different from other information systems is the type of information that is handled: geographic location. With a GIS you can know the quantity and quality of something and the **location** of that event, activity, or feature. For example, you might have recorded your heart rate and timed your morning jog using your phone or other fitness tracking device. Since you also have the location or coordinates of your jog, you can calculate or derive additional information such as speed (distance per time), the total distance you jogged, and also your elevation above sea level. You could even relate your heart rate to different locations along your jog to better understand your performance on different terrain. This is an example of a GIS at work. You are storing geographic information into a system that allows you to code the information with different qualities (e.g., the type of surface your ran on) and quantities (e.g., your heart rate) and then recall that information in a way that allows you to explore trends and ask and answer **spatial** questions.

Chapter 2

Mapping Data

You probably already accept that the Earth is "round" and not "flat". You have probably held and touched a globe at some point in your life. But have you ever wondered how we describe location and measure something as large as the Earth? In this chapter, we will explore fundamental concepts for how we measure the Earth and orient ourselves with coordinate systems.

Learning Objectives

1. Understand the models of Earth's figure and shape
2. Describe different vertical datums and how they are used to reference height
3. Understand the difference between cartesian, celestial, geographic, and projected coordinate systems
4. Recognize the differences among major types of map projections
5. Explore how projected coordinate systems distort and represent the world around us

Key Terms

Antipode, Great Circle, Small Circle, Geodesy, Vertical Datum, Horizontal Datum, Deflection of the Vertical, Ellipsoid, Spheroid, Geoid, Elevation, Orthometric Height, Geoid Height, Geodetic Height, Coordinate System, Celestial Coordinate System, Cartesian Coordinate System, Geographic Coordinate System, Projected Coordinate System, Map Projection, Tissot's Indicatrix

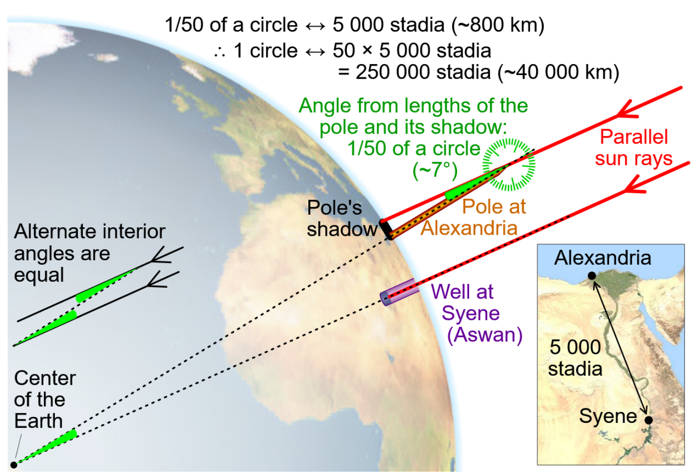
2.1 Introduction to Geodesy

Geodesy is the fascinating science of measuring the shape, orientation, and gravity of Earth. Naturally, some of the questions that come to mind when thinking about such a grand topic are *I thought the shape of Earth is a sphere?* and *How do we orient ourselves on Earth?* and *What does gravity have to do with mapping location?*

All of these questions stem from need to represent **location**. For our purposes, location is the position of something relative to something else. In order to actually describe a location on Earth, we first need to know the size and shape of Earth. Some of the first estimations of Earth's size and shape were made by Eratosthenes, a Greek mathematician from the second and third centuries B.C. Eratosthenes was responsible for many concepts we use in our everyday lives:

- Conceiving the first spherical model of Earth
- The first accurate measure of Earth's circumference
- Calculating the tilt of Earth's axis
- Calculating the distance of Earth to the Sun
- Invention of the leap day

Eratosthenes accurately calculated the circumference of Earth by noticing how the Sun shone directly down the bottom of a well in Syene (modern Egypt) at noon on the summer solstice. He later made a second observation at Alexandria at noon on the summer solstice with a pole and noticed a shadow. He measured the angle of the shadow and inferred the circumference of Earth, which was already known to be spherical (Figure **??**).



\begin{figure}
\caption{Diagram showing how Eratosthenes estimated the circumference of Earth by observing the angle of a shadow that was cast about 800 km north of Syene in present-day Egypt. (**?**), CC-BY-SA-4.0.} \end{figure}

Pretty simple, right? Turns out, Eratosthenes was off by only 75 km or less than 0.2% in his calculation! The actual North-South circumference of Earth is about 40,075 km. His calculation worked because the Sun's rays are nearly parallel when they strike Earth. So if you observe the Sun at the same time in two locations on Earth on the North-South axis, you will notice the Sun has a different elevation above the horizon, which means different lengths of shadows will be cast on the ground. This is also a way to prove that the Earth is in fact round because a flat Earth would have equally-sized shadows everywhere at any given time of day.

2.2 Models of Earth

Here is a simple thought experiment to consider. Suppose you are trying to measure your own height. You probably have not given much thought about how to technically do this because it seems intuitive: place a measuring tape at the bottom of your feet and mark the measurement at the top of your head. If we break this down, there are some important rules to follow (Figure **??**):

1. The measuring tape must originate somewhere. In other words, we need to define a reference point or surface of zero height (i.e., the ground).
2. The measuring tape must be a straight line and originate at a 90-degree angle, perpendicular to the ground.
3. The measurement must terminate at a point along an imaginary line that is tangential to your head, and yes, that line must be perpendicular to the measuring tape and also parallel with the ground.

Whenever you measure your height, the ground is easy to define. It is whatever point you are standing on. This starting point it also known as a **datum**. A datum is simply a reference point, set of points, or a surface from which distances can be measured. It does not matter if you are below sea level, atop Mount Everest, or on the 30th floor of a skyscraper. You will always get an accurate and repeatable measure of your height using a datum that is defined directly below your feet. But what about measuring the height of terrain on Earth? Whenever we measure the height of Earth's terrain above some reference surface, we are measuring **elevation**.

The same rules above apply when we measure elevation. In order for elevation measurements to be comparable across the world, we need to define a reference surface, a datum, for the entire planet. There are actually several ways that we can model the shape of Earth in order to produce a datum. Models of Earth's shape are often referred to as either vertical datums (the plural of datum) if you are referencing elevation or horizontal datums if you are referencing location. A **vertical datum** is a 3D surface model that is used to reference heights or elevations for the Earth. A simple question like *How high is Mount Logan in Yukon, Canada?* is complicated by the need for a reference surface and the fact that Earth's shape is irregular. In this section, we will review three types of vertical datums:

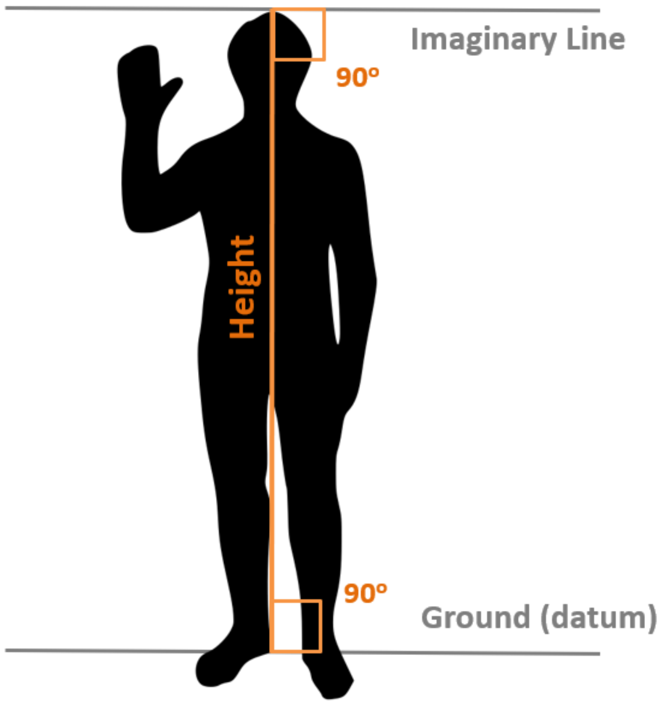


Figure 2.1: Diagram for measuring height above a datum. Pickell, CC-BY-SA-4.0.

- Geodetic - based on geometry
- Tidal - based on sea level
- Gravimetric - based on gravity

2.2.1 Geodetic Vertical Datums

A **geodetic vertical datum** is one that describes the Earth's shape in the simplest possible terms using standard geometry. Despite what a globe might lead you to believe, the Earth is not perfectly spherical, but it is close to being spherical. In fact, the radius of Earth varies by no more than 22 km or 0.35%, hardly anything you would ever notice if you were holding it in your hand. That small difference is, however, significant enough to lead to mapping inaccuracies at the local level if a spherical model of Earth was adopted (Figure **??**). Instead, we frequently describe Earth's shape as an oblate ellipsoid, which is essentially a sphere that has been flattened, and we define this ellipsoid with a semimajor and semiminor axis. Sometimes you will see the term *spheroid* used, which just means "sphere-like" and is interchangeable with the term *ellipsoid*.

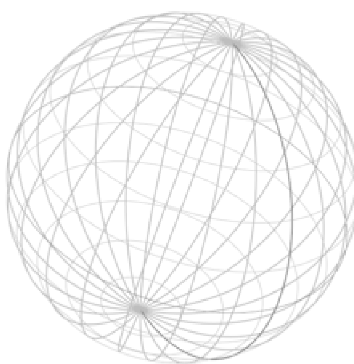


Figure 2.2: Spherical geodetic datum. Pickell, CC-BY-SA-4.0.

There are many different ellipsoids that have been defined and are currently in use as datums. The most commonly used ellipsoid is called the World Geodetic System of 1984 or usually abbreviated as WGS 1984 or WGS 84. In fact, there are hundreds of ellipsoids that have been defined over recent centuries to model the shape of the Earth. The reason for so many other ellipsoids is due in part to technological advances that have improved the accuracy and precision of surveying as well as estimation of the ellipsoidal parameters. Many of these ellipsoids are not **geocentric**, that is, not originating from the center of mass of Earth. These datums are known as **regional datums**, which still describe the dimensions that approximate the shape of Earth, but are instead oriented so that the surface of the ellipsoid is congruent with a particular regional surface of Earth. For example, the European Datum 1950, the South American Datum 1969, the North American Datum 1983, and the Australian Geodetic Datum

1966 conform well to their respective continents, even better than WGS 1984 in most cases, but poorly anywhere else in the world.

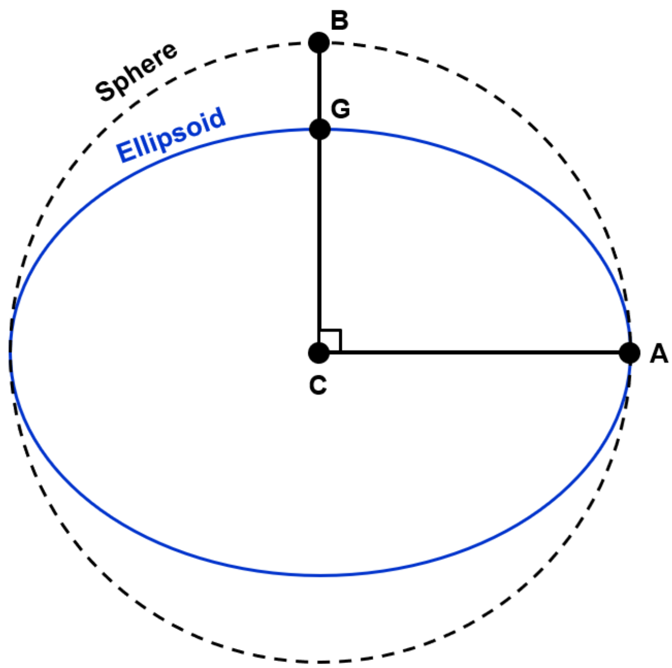


Figure 2.3: Sphere versus ellispoid. Pickell, CC-BY-SA-4.0.

Figure **??** greatly exaggerates the flattening of the ellipsoid to illustrate the above points. In reality, the sphere is flattened using a flattening factor calculated as $f = (CA - CG)/CA$ and defined exactly as $f = 298.257223560$ for WGS 1984. Thus, the semiminor axis (i.e., rotational axis) for the WGS 1984 ellipsoid (meters) is

$$CG = CA - (CA \times \frac{1}{f}) = 6378137 - (6378137 \times \frac{1}{298.257223560}) = 6356752.3$$

where G is the North Pole and A is a point on the Equator. The sphere, of course, is much simpler where $radius = CB = CA = 6378137$.

2.2.2 Tidal Vertical Datums

A **tidal vertical datum** is likely one that you are familiar with. The premise of a tidal vertical datum is to use mean sea level as a reference surface, above which are positive elevations and below are negative elevations. This has a lot of advantages, like it is intuitive and oceans cover more than 70% of the planet's surface so much of Earth's land mass is near an ocean. However, the disadvantages are that sea level changes over time with tides and also with climate change. The not-so-obvious problem with a tidal vertical datum is that the sea level is actually not constant around the planet not only due to tides, but also temperature, air pressure, and gravity. In other words, mean sea level measured at a gauge station in Halifax on the Atlantic Ocean will not be the same distance from the center of Earth as mean sea level measured at Victoria on the Pacific Ocean (Figure ??). The primary challenge with a tidal vertical datum is extending it away from the coastline through a network of survey points using a process known as levelling, and even still, it is only meaningful during the epoch in which the mean sea level was measured at a number of tidal gauge stations.

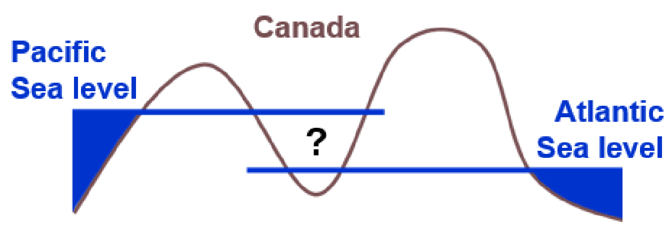


Figure 2.4: Conceptual tidal datum for Canada. Pickell, CC-BY-SA-4.0.

2.2.3 Gravimetric Vertical Datums

The **geoid** is a physical approximation of the figure of Earth. The shape represents Earth's surface with calmed oceans in the absence of other influences such as winds and tides. It is computed using gravity measurements of Earth's surface and is best thought of as the surface or shape that the oceans would take under the influence of Earth's gravity and rotation alone. In other words, the geoid represents the shape Earth would take if the oceans covered the entire planet. More specifically, the geoid is a **gravimetric** model of Earth's shape that is defined as an equipotential surface from a constant gravity potential value. Due to the distribution of mass on Earth, gravity is not constant across the planet's surface. As a result, the surface of Earth's oceans is not smooth like a sphere, but instead undulates depending on where gravity forces water to remain at rest. You can think of Earth's gravitational field as a series of parallel lines extending outwards from the center of mass of Earth into space. Any of these lines that you choose is an equipotential surface where the force of gravity is constant. Keep in mind that the force of gravity is stronger nearer the center of mass of Earth and weaker as you move away from it. Thus, the geoid is an arbitrary equipotential gravity surface that is chosen to roughly coincide with present-day mean sea level.

When you measure the height of something relative to a gravimetric vertical datum like the geoid, you must level your instrument. Levelling forms a vertical line that is orthogonal or perpendicular to the geoid, known as a **plumb line**. It is incredibly easy to visualize a plumb line. Simply tie a rock to the end of a string and hold the string with your outstretched arm. The length of the straightened string traces a plumb line to the center of mass of Earth, wherever you are. Because gravity changes with location on Earth and all plumb lines are converging on a singular point, plumb lines are never parallel. This phenomenon has important implications for comparing observations on the the ground with a geodetic model of Earth like an ellipsoid. In other words, the plumb line that you traced with your string is pointing to the center of mass of the geoid, but the center of the ellipsoid is often in a slightly different direction. This difference is known as the **deflection of the vertical** and is measured as the angular difference between the centre of the geoid and the centre of a reference ellipsoid. Like other measurements of geodetic location (i.e., latitude and longitude), the deflection of the vertical is comprised of two angles: ξ (xi) representing the north-south angular difference and η (eta) representing the east-west angular difference.

It should be evident by now that the reference surface that you choose as a vertical datum will determine the measured elevation of Earth's terrain. Additionally, We frequently need to convert elevations between geodetic and gravimetric vertical datums. For example, when you use a Global Navigation Satellite System receiver, you are provided with an elevation that is relative to the WGS 1984 ellipsoid (more on that in Chapter 4). The difference in height between an ellipsoid and the geoid is referred to as **geoid height (N)** while the difference in height between an ellipsoid and Earth's surface is referred to as **geodetic or ellipsoidal height (h)**. The difference in height between the geoid and the Earth's surface is called **orthometric height (H)** (Figure **??**), and is given as:

$$H = h - N$$

To illustrate the concept of a gravimetric datum, suppose we constructed a large, straight tunnel through the physical Earth that was tangential to the ellipsoid. If we allowed the oceans to flow freely through this tunnel, your experiences might convince you that water would flow from one end to the other. But in fact, this tunnel is so large, that the gravity field is changing. So the water would actually come to rest at the surface of the geoid or gravimetric model, as shown in Figure **??** below.

2.3 Case Study: The Canadian Geodetic Vertical Datum of 2013

The Canadian Geodetic Vertical Datum of 2013 (CGVD2013) is the current gravimetric vertical datum used in Canada to reference heights. It is defined with a potential gravity value of 62,636,856.0 m^2 s^-2. The pervious vertical

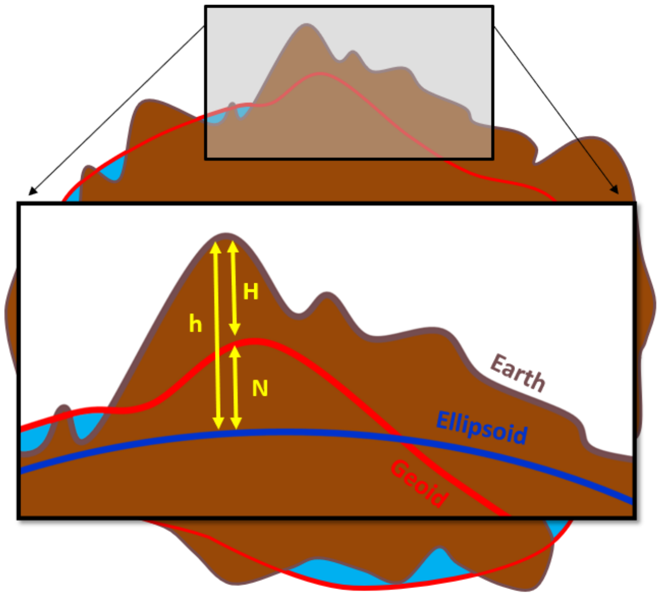


Figure 2.5: Orthometric Height (H) is the ellipsoidal height (h) less the geoid height (N). Pickell, CC-BY-SA-4.0.

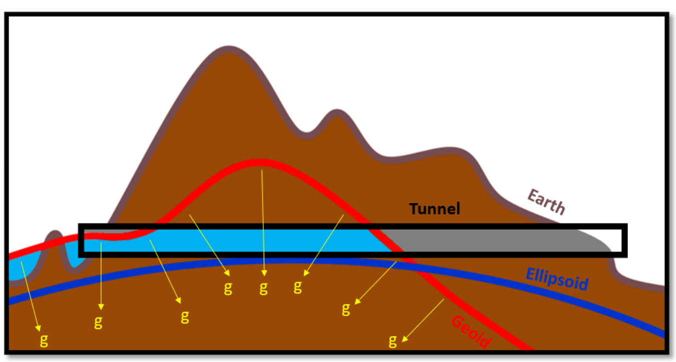


Figure 2.6: Thought experiment showing where water would be at rest within a tunnel through the geoid due to the equipotential force of gravity (g). Pickell, CC-BY-SA-4.0.