Earth Science Applications of Space Based Geodesy

DES-7355

Tu-Th 9:40-11:05

Prefer - Seminar Room in 3892 Central Ave. (Long building)

Bob Smalley
Office: 3892 Central Ave, Room 103
678-4929

Office Hours – Wed 14:00-16:00 or if I' m in my office.

http://www.ceri.memphis.edu/people/smalley/ESCI7355/ESCI_7355_Applications_of_Space_Based_Geodesy.html

Class 1

GRADING

70% homework assignments

approximately weekly

Each assignment will be passed out 1-2 weeks before it is due and should be worked on throughout the given time period

10 % Attendance and participation

GRADING

20% Final Project

Each student will design, implement, and present a small scale space-based geodesy research project.

A project related to the student' s own research is encouraged.

Topic should be decided on and approved no later than October 9, 2012.

GRADING

Final Project

Presentation of results (20 mins.) will take place in lieu of a final exam on the last day of class - Dec. YY.

The project should be thoroughly documented and all scripts/programs/macros will be turned in as part of the final grade.

Academic Honor Code

It is acceptable to work together/help one-another on homework to better understand the material.

It is acceptable (it will actually be essential) to refer to other books and published material provided that these additional materials are cited appropriately in the homework (including web sites).

Each student should complete their own homework separately.
Simply copying the homework of another student or a single "group" homework is NOT acceptable.

No textbook

~

We will have reading assignments from a number of sources.

Class notes will be available in pdf format, after class, on the class website.

http://www.ceri.memphis.edu/people/smalley/ESCI7355/ESCI_7355_Applications_of_Space_Based_Geodesy.html

Please let me know if there are any problems with the web page.

Note that the notes are not "static", I will update them from time to time.

Please do not blindly print the notes out.

(I will remove the background from the notes to save yellow toner.)

Some things you should buy if you are planning on using GPS in your research

Basic

Linear Algebra, Geodesy and GPS, Strang and Boore

Some things you should buy if you are planning on using GPS in your research

geodetic and technical

GPS Theory and Practice, 5th Revised Ed., B. Hofmann-Wellenhof, H. Lichtenegger, and J. Collins, Springer-Verlag, Wein, New York, 2001.

Other books

geodetic and technical

Understanding GPS Principles and Applications, 2nd Ed., E.D. Kaplan, C. Hegarty (eds.), Artech House, 2006.

Global Positioning System: Theory and Applications, Volume 1 & 2, B. W. Parkinson, J. Spilker (Eds), Am. Inst. Aeronaut. Astronaut., Washington D.C., 1996.

Stuff from the internet

Tutorial – Ellipsoid, geoid, gravity, geodesy and geophysics

X. Li and H-J Götze

Geophysics, Vol 66, No 6, 1660-1668, Nov-Dec 2001.

www.lct.com/technical-pages/pdf/Li_G_Tut.pdf

More stuff from the internet

D. Sandwell

GEODYNAMICS- SIO 234

http://topex.ucsd.edu/geodynamics

Units 14 (2 parts), 15 (2 parts) and 16 (all on gravity).

More stuff from the internet

Basis of the GPS Technique: Observation Equations

G. Blewitt

Appears in "Geodetic Applications of GPS", Swedish Land Survey.

http://www.nbmg.unr.edu/staff/pdfs/Blewitt%20Basics%20of%20gps.pdf

More stuff from the internet

GPS Data Processing Methodology: from Theory to Applications

G. Blewitt

GPS for Geodesy, p231-270, Springer-Verlag

http://www.nbmg.unr.edu/staff/pdfs/gps%20for%20geodesy.pdf

More stuff from the internet

GPS and Space Based Geodetic Methods

G. Blewitt

chapter in Treatise on Geophysics, Vol. 3., pp. 351-390, 2007.

Ed. Thomas Herring, Ed.-in-chief Gerald Schubert, Academic Press, Oxford, UK, ISBN: 0-444-51928-9.

http://www.nbmg.unr.edu/staff/pdfs/blewitt_treatise.pdf

More stuff from the internet

GPS Positioning Guide

Available from

Natural Resources Canada

http://www.geod.nrcan.gc.ca/publications/papers/gps_e.php

(plus lots other stuff)

1. Introduction.

Course objectives and overview

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1) Understanding and appreciation of modern (satellite based) Geodesy.

2) Ability to use tools of modern Geodesy.

3) <u>Ability to use results of modern Geodesy in multi-disciplinary studies.</u>
~~~~~~

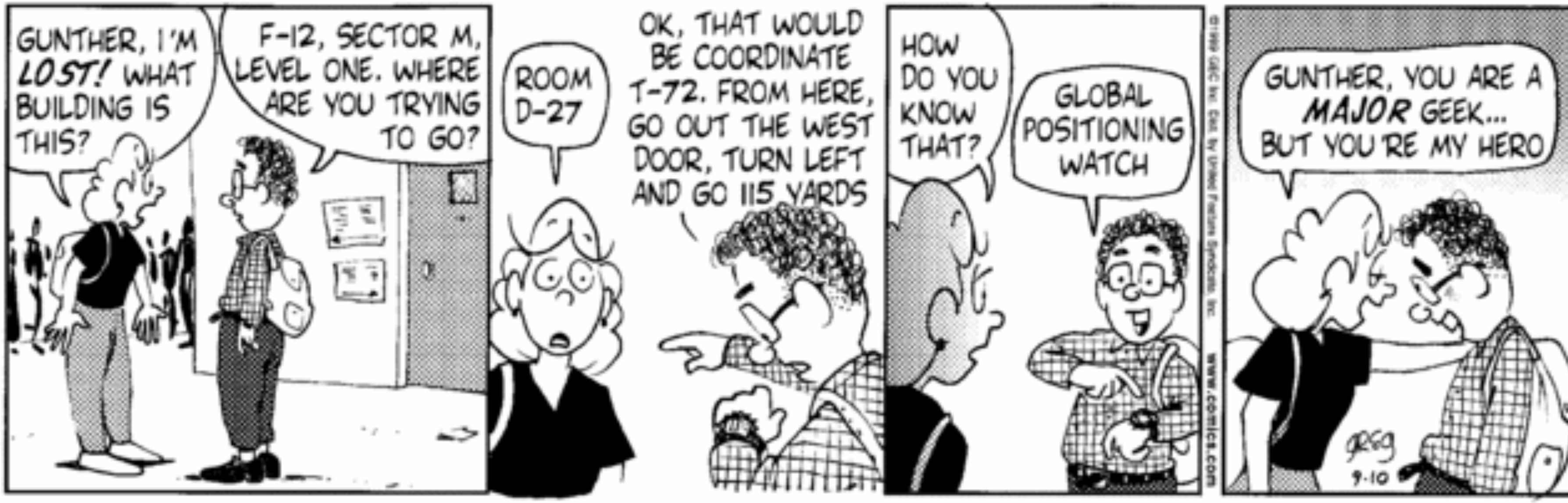
Outline:

Shape of the Earth
Physical vs. Geometric description (reference frame/ Coordinate system)
Time

How GPS works ("trivial" overview)
How GPS works (technical)
[orbits, estimation, observables, propagation, errors]

Processing

Applications – modeling



I’ve never been lost. I was once bewildered for three days, but never lost!

Dan’l Boone

1. What is Geodesy?
(Good question)

One of the basic questions has always been

Where am I? (cave, watering hole, etc.)

Which leads to

Where am I going (watering hole, cave, etc.)

and

How do I get there?

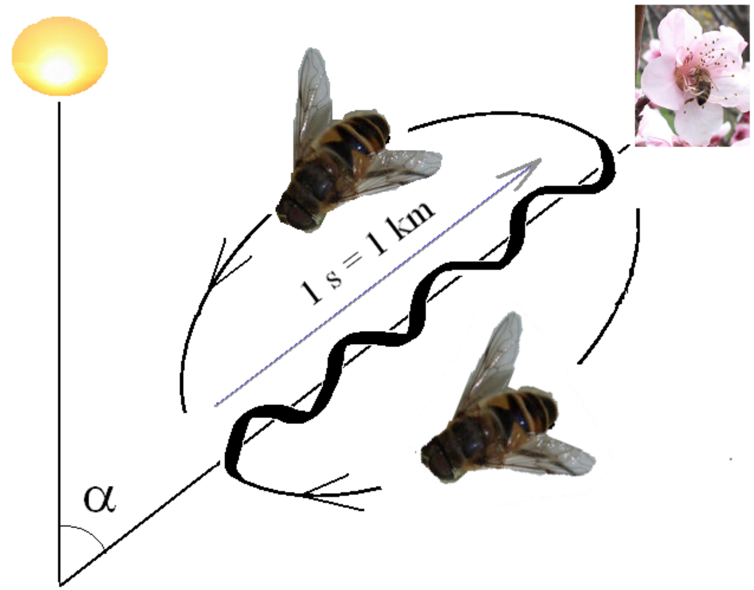
1. What is Geodesy?

(Good question)

How do I get there?

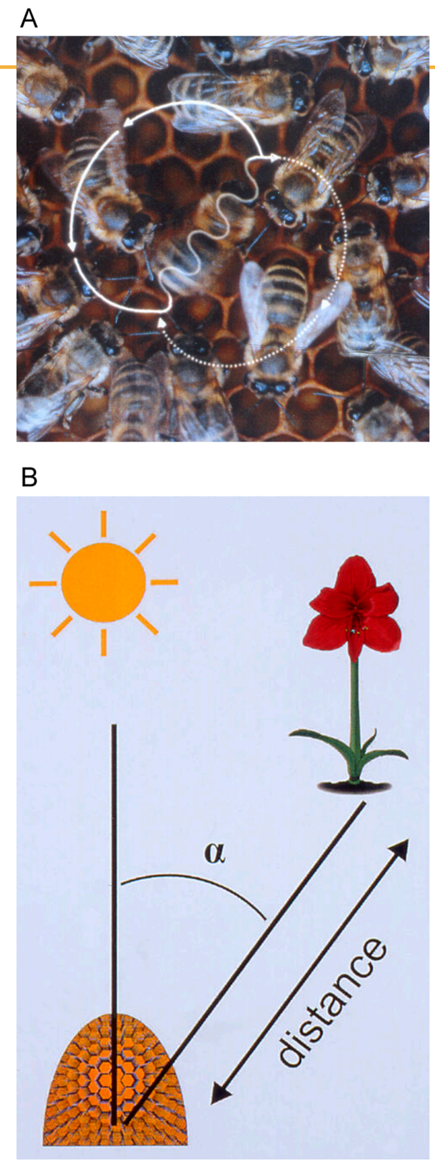
Or how do I tell someone else how to get there (without bringing/leading them)?

One solution - Honey bee dance



http://commons.wikimedia.org/wiki/File:Bee_dance.png

Scout bee "tells" forager bees location of nectar source.
Requires personal contact (oral tradition) and is ephemeral.



http://en.wikipedia.org/wiki/Waggle_dance

A waggle run oriented 45° to right of 'up' on the vertical comb (A) indicates food source 45° to right of direction of sun outside hive (B).

Note: uses a <u>reference frame</u>

1. What is Geodesy?

(Good question)

How do I get there?

Or how do I tell someone else how to get there (without bringing/leading them or having personal contact)?

Early solution

Mark trail (permanent)
(or use landscape features)

Another idea

Draw a picture

"Oldest" known "map"

Catal Hyuk, Turkey/Anatolia
(Catal Hyük , Çatalhöyük, Catalhoyuk)
9' long wall painting. Radiocarbon date 6200 BC

Writing didn't come along till 3500BC!

This idea, when applied on large scale also gives – world view

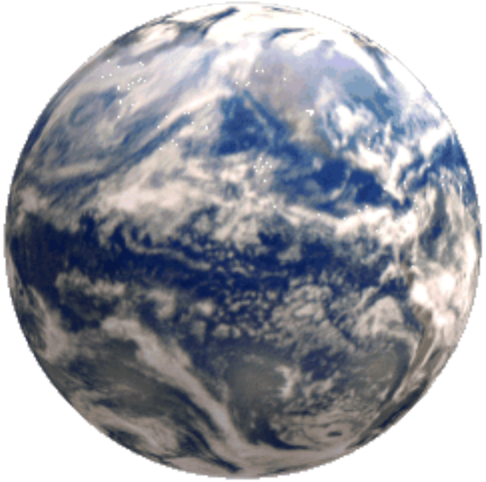
Example -

Homer's view of the world

1. What is Geodesy?

(Good question)

Quite simply 'Geodesy' is the study of the shape and size of the earth.

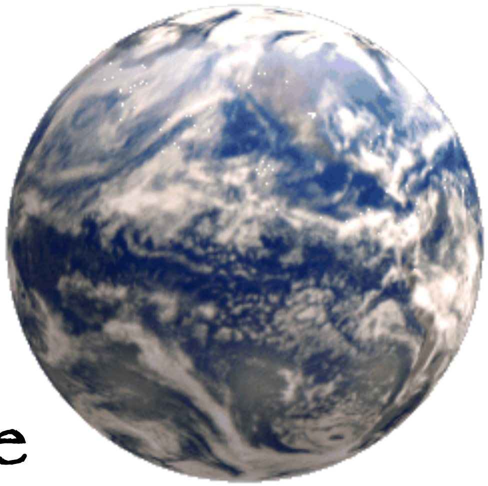


Now I bet you're thinking to yourself, "Hey, I've seen pictures of the earth from space, from the Apollo Moon Missions, from the Shuttle, and the earth looks/seems round to me."

1. What is Geodesy?

(Good question)

Quite simply 'Geodesy' is the study of the shape and size of the earth.



So, what's to study?

Well, the earth is almost round, but not quite. And, because the earth's not quite round, we need to know just what shape it is, so we can make accurate maps (and other stuff).

1. What is Geodesy?

Geodesy, traditionally defined as the study of the shape of the earth

from Greek - ge daisi : ge -, geo- earth + daiesthai, to divide

determining size/shape of earth
[at a scale of 1:1!]

and accurate positioning/mapping

Geodesy is among the oldest of sciences.

1. What is Geodesy?

Geodesy, also traditionally includes the study of earth's gravity.

why?

1 - At large scale gravity is the physics controlling earth's shape
(earth is "fluid" in hydrostatic equilibrium)

2 - and gravity also has significant effects on the traditional methods of measuring the earth's shape.

1. What is Geodesy?

"…physical geodesy – the shape of the Earth and its gravity field.

This is just electrostatic theory applied to the Earth, but, unlike electrostatics, geodesy is a nightmare of unusual equations, unusual notation, and confusing conventions.

There is no clear and concise book on the topic although Chapter 5 of Turcotte and Schubert is OK."

From David Sandwell, U. Hawaii

1. What is Geodesy?

Modern Geodesy

- continuation of traditional studies

plus

- significant expansion based on

new technology

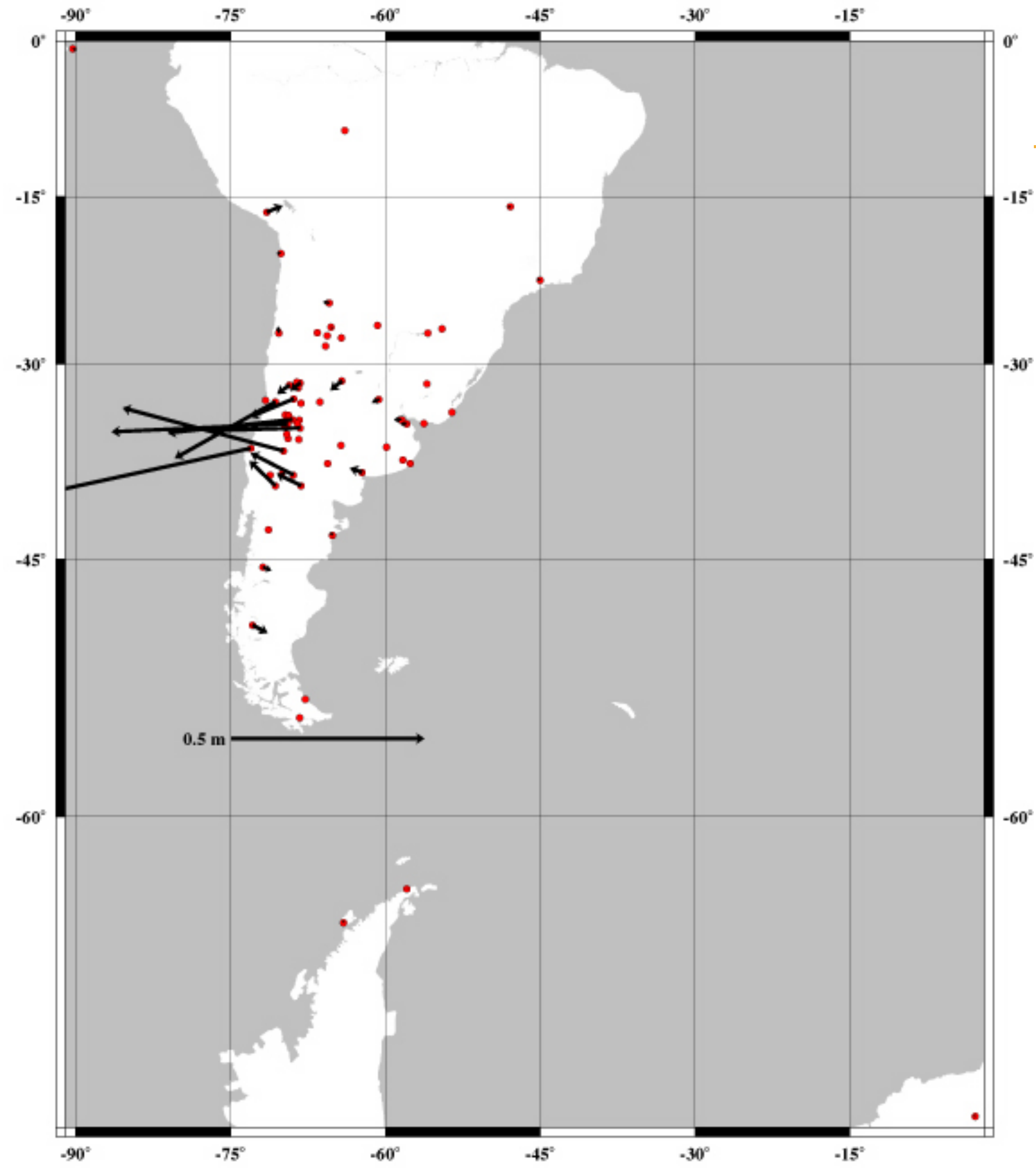
providing a several order magnitude improvement in surveying capability through the use of space based surveying techniques

1. What is Geodesy?

Modern Geodesy

paradigm change to include changes in earth’ s shape

(plate movements, plate boundary deformation, [G]IA, elastic loading, earthquakes, etc.)



Example:

Co-seismic displacement associated with 27 Feb, 2010, M8.8 Maule, Chile earthquake.

Up to 5m displacement of coast, 50 cm in Mendoza and 2.5 cm in Buenos Aires, over 1000 km distant.

New term (just in case it's not confusing enough):

Geomatics

-- Refers to the disciplines that acquire, store, manage, retrieve, manipulate and distribute spatial or geographically referenced data. (basically GIS)

-- Field of scientific and technical activities which integrates all means used to acquire and manage spatially referenced data. (GIS again)

-- new name for Surveying or Geodesy

-- Mathematics which deal with the earth.

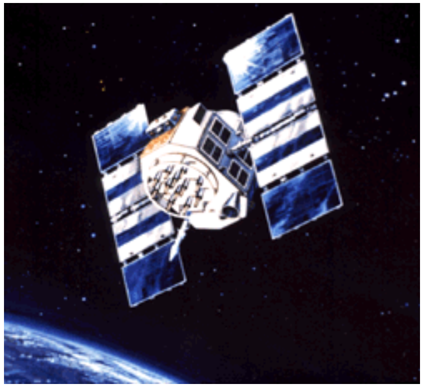
What is Satellite Geodesy?

Application of satellite surveying/measurement techniques to "Geodesy" (positioning, mapping, and study of size, shape and gravity field of earth)

(GPS/GLONAS/DORIS/GALELIO/BEIDOU-COMPASS/IRNS/JRANS, SLR, VLBI, Satellite Altimetry, Doppler)

collectively called

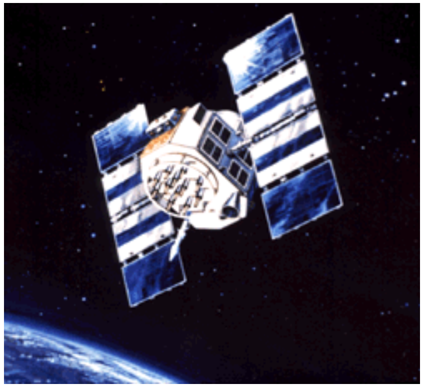
-- GNSS --



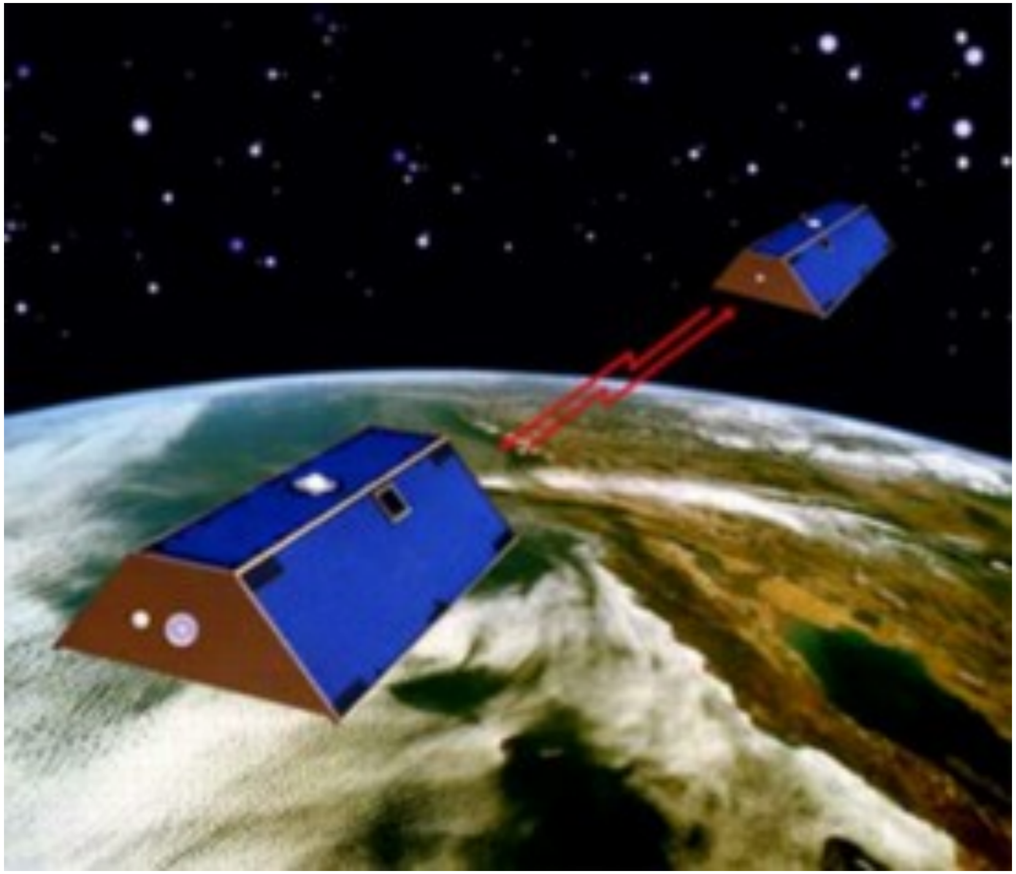
Global Navigation Satellite Systems

What is Satellite Geodesy?

New definitions of "Geodesy" based on increase in precision (e.g. time variations from motions associated with Plate Tectonics, Tides, Weather/Climate, etc.)



Satellite surveying techniques



GPS/Galileo/GLONAS…

VLBI

SLR

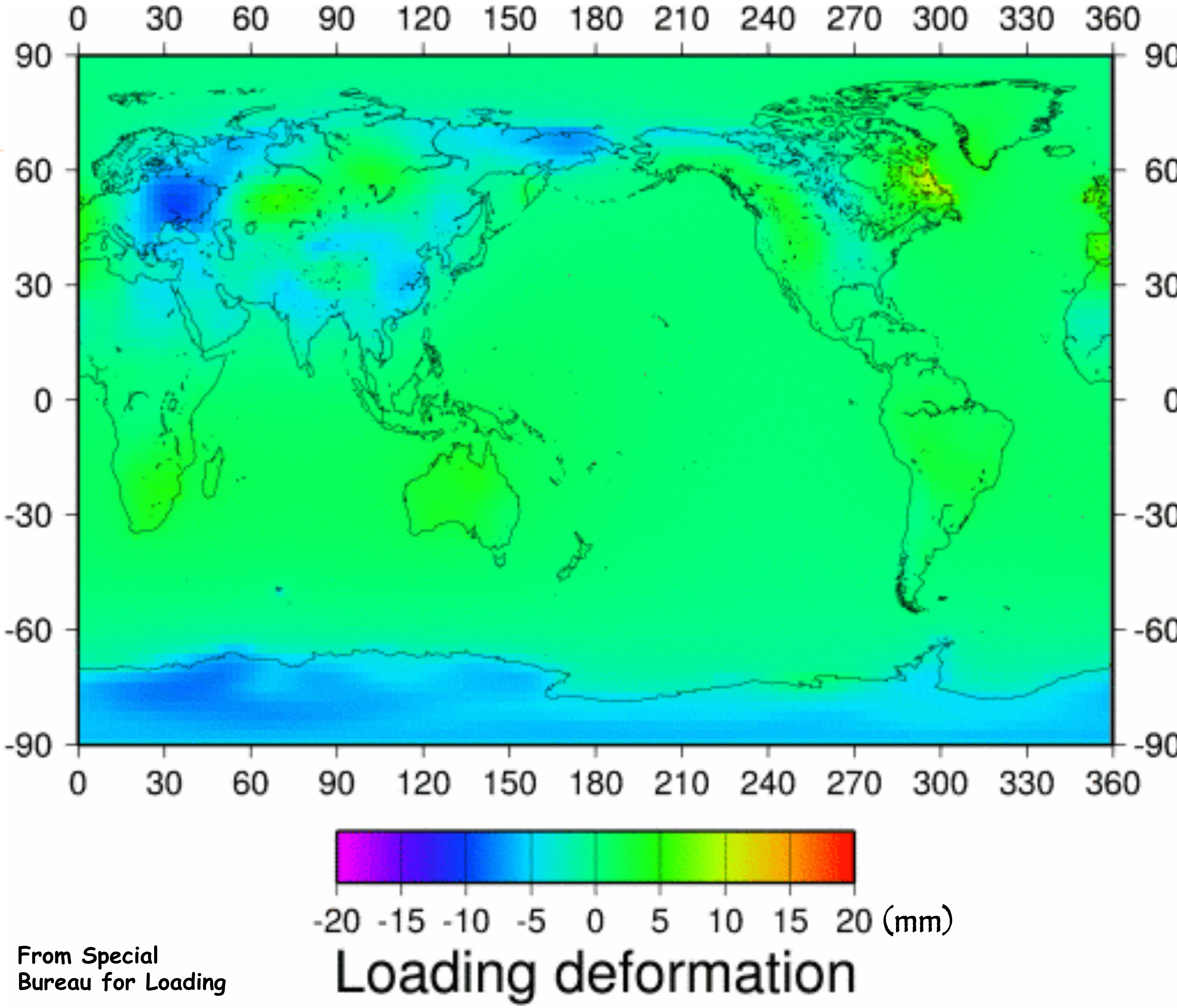
DORIS

Doppler

Satellite Altimetry

SAR

CHAMP/GRACE/etc.

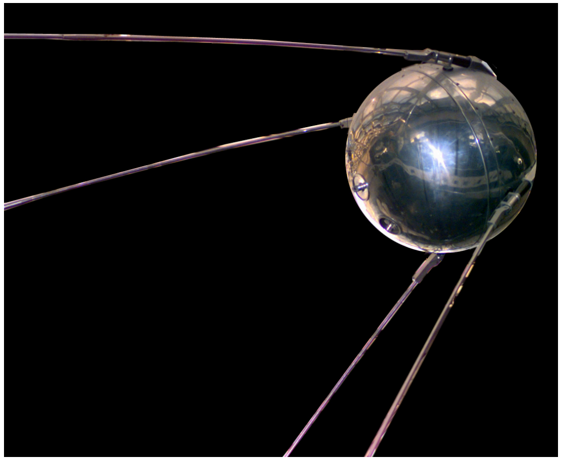


From Special
Bureau for Loading

Introduction to GPS system

Positioning/navigation/time transfer system designed, built and funded by US DOD.

(Follow on to TRANSIT Doppler – inspired by SPUTNIK!)



Introduction to GPS system

Positioning/navigation/time transfer system designed, built and funded by US DOD.

After KAL 007 "incident" in 1983, President Regan ordered that GPS system design include degraded version for civilian use to prevent reoccurrence of similar navigation errors.

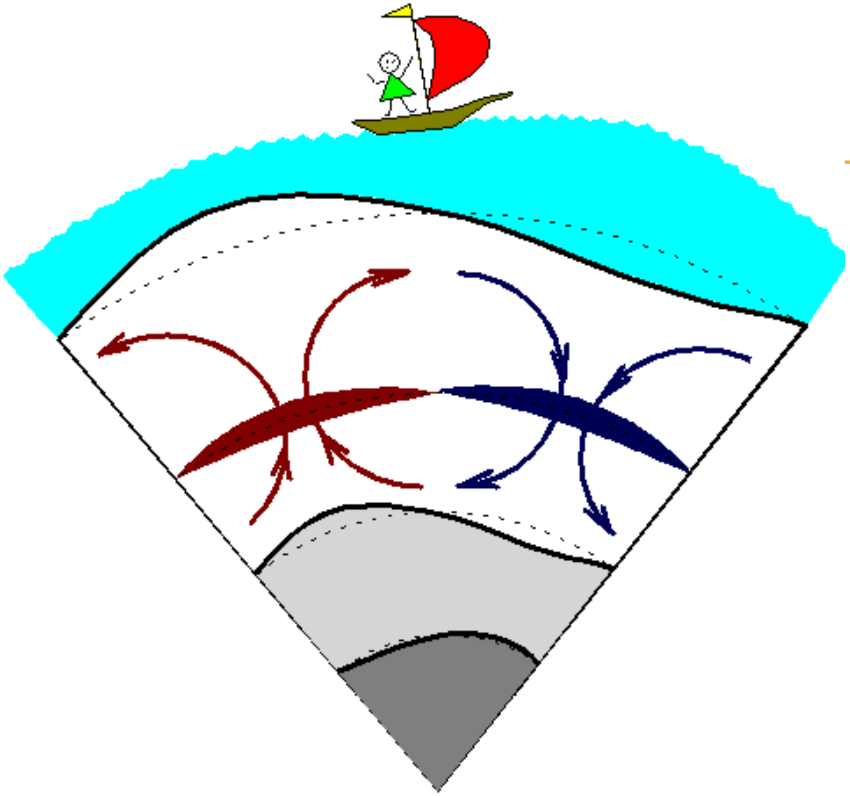
Introduction to GPS system

Positioning/navigation/time transfer system designed, built and funded by US DOD.

somewhat unforeseen and definitely unplanned

Explosion of civilian use based on principally ground based technological/engineering developments

Applications GNSS and Space Based Geodesy:



Notice – inner and outer core not spherical, temperature/density variations in earth, topographic variations (long wavelength ones may be related to above temperature/density variations), sea level not "level" (also may be related to density variations), etc.

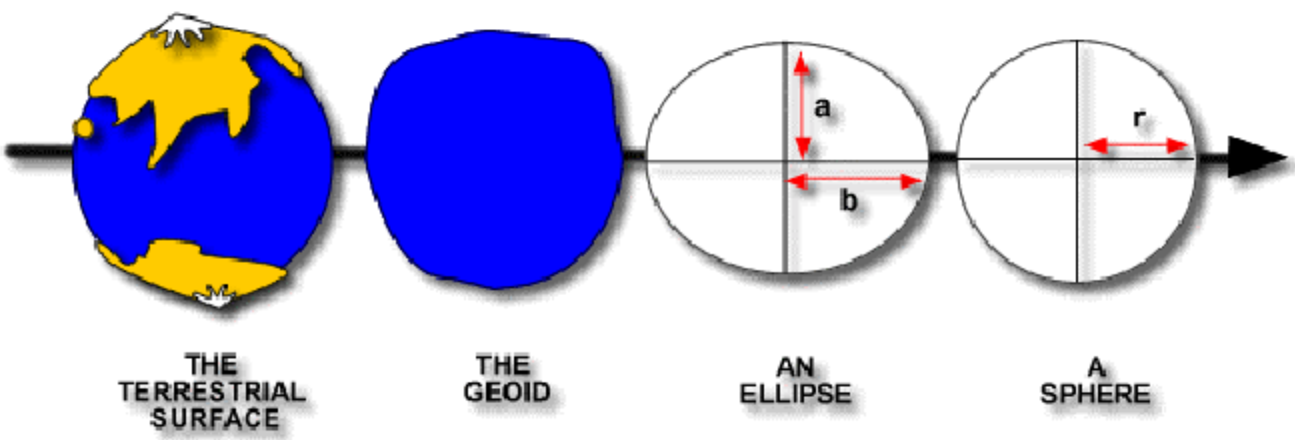
Navigation
Crustal dynamics/Active tectonics
Gravity field mapping
Reference frames
Sea level/Climate change
Earth rotation
GPS "met"
Atmospheric occultation
Ionospheric physics
Space weather
Geodetic seismology

2. Geodesy

Shape of the earth/gravity, geoid (physical),

reference frames, ellipsoids (geometric)

The Figure of the Earth



From Mulcare

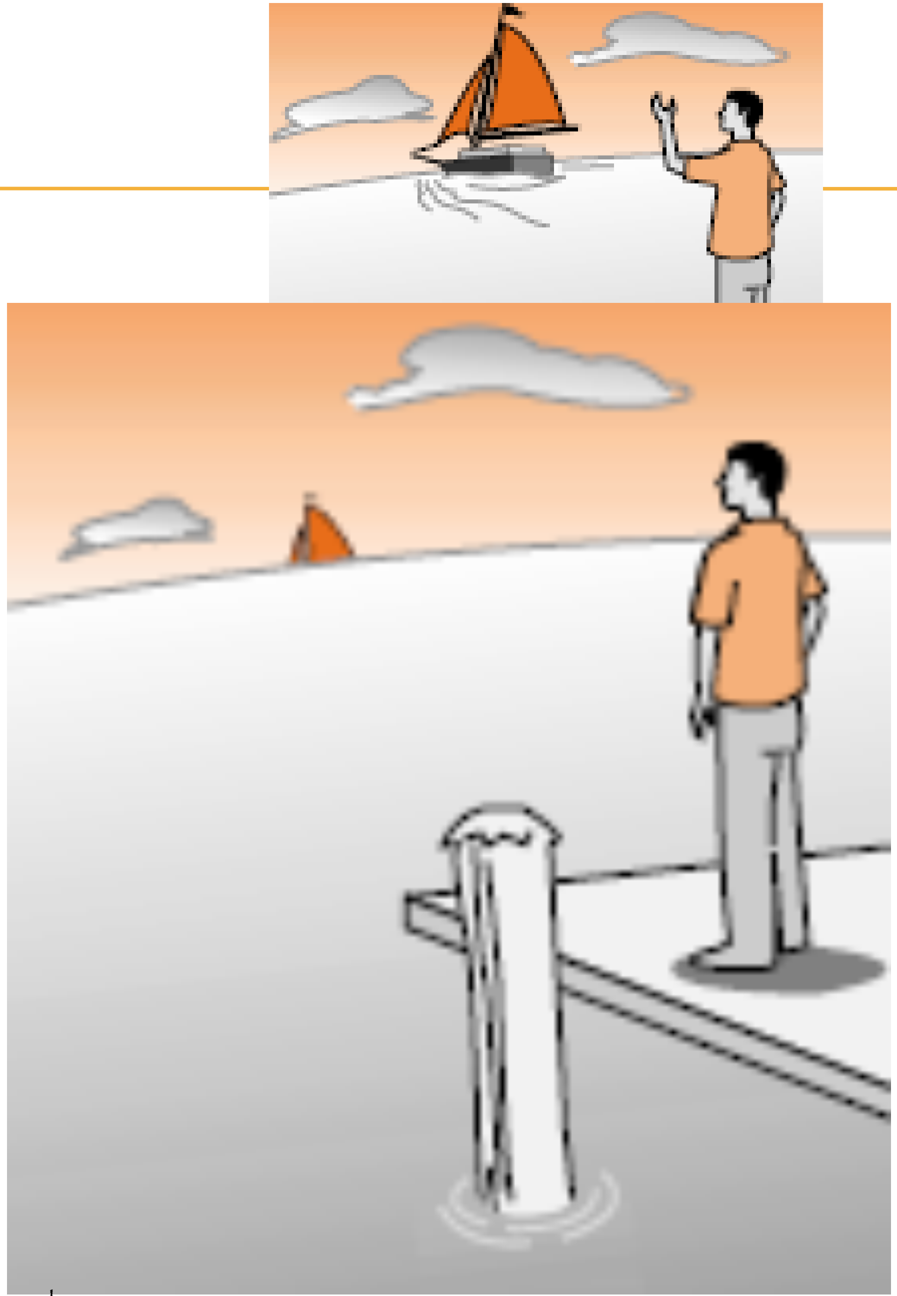
Shape of the Earth

To an observer on the surface, the earth looks flat and endless.

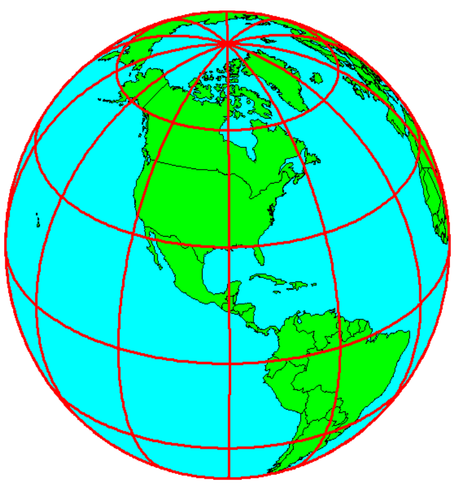
(so that was the first "model")

http://www.amscopub.com/%5Cimages%5Cfile%5CFile_46.pdf

Shape of the Earth



We now think of the earth as a sphere



Some evidence for spherical shape:

As ships sail over the horizon, they "disappear".

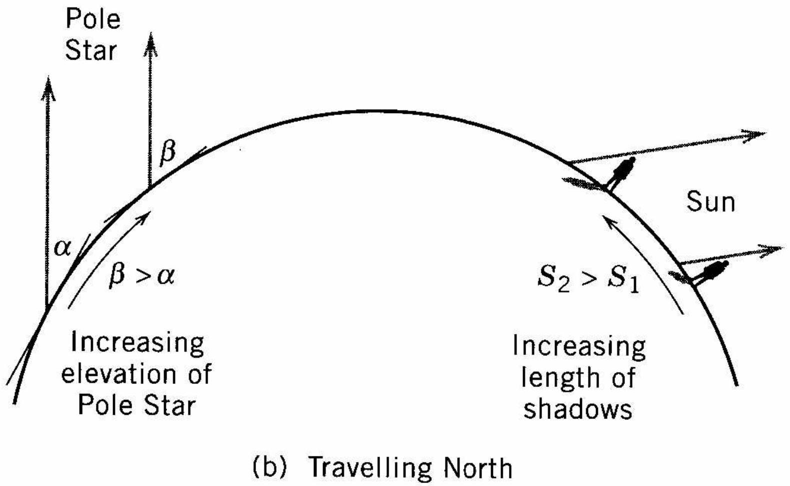
Geodesy and Map Projections, Benedict, doctorflood.rice.edu/envi512/handouts/CEVE512_Lab3.ppt
And
http://www.amscopub.com/%5Cimages%5Cfile%5CFile_46.pdf

Shape of the Earth

Some evidence:

Changing elevation of star/sun as travel north or south.

(could also be cylinder!)



1. Realizing the Earth Is Not Flat

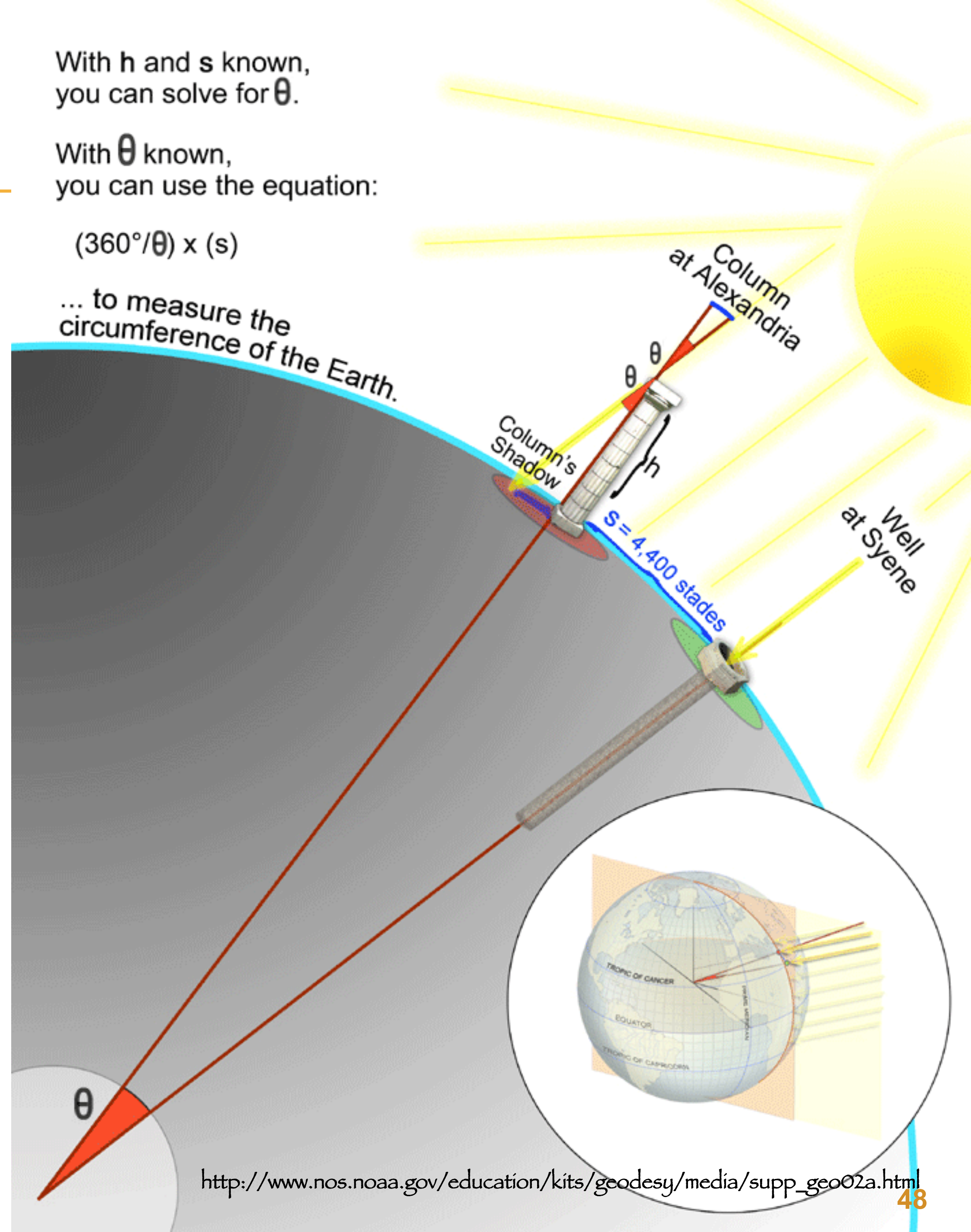
Smith, Intro to Geodesy

Size of the Earth

Once the shape was "known", the size could be calculated from geometry and simple observations

Eratosthenes, 230 B.C.

("knew", assumed, or used without thinking – parallelism of sun's rays, etc.)



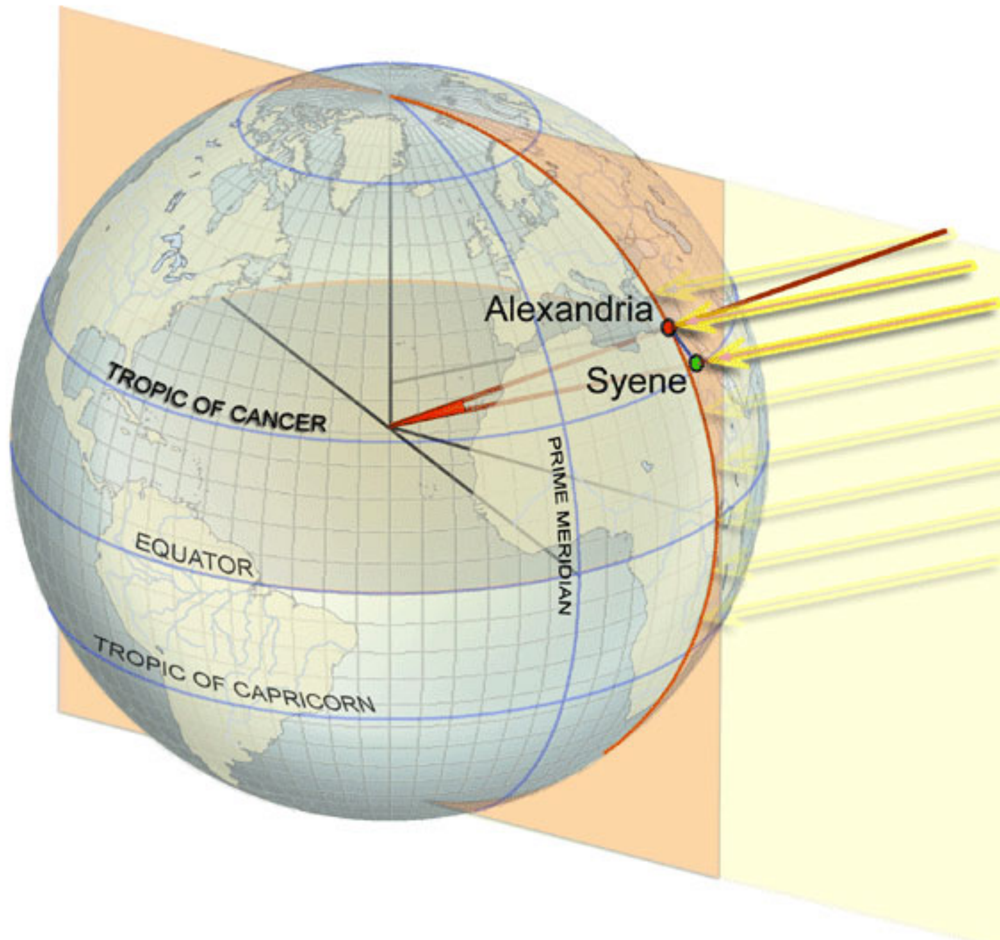
http://www.nos.noaa.gov/education/kits/geodesy/media/supp_geo02a.html

Size of the Earth

Eratosthenes' calculations were based on two assumptions.

The first was that Syene lay on the Tropic of Cancer.

The second was that Alexandria lay due north of Syene on exactly the same line of longitude (the meridian line).



http://www.nos.noaa.gov/education/kits/geodesy/media/supp_geo02a.html

Eratosthenes was roughly correct about the size of the Earth

-- at least, that's what modern historians of science have concluded,

although there is apparently some lingering doubt about the exact size of the units of measurement (stade = 184.81 m) which he was using.

And his two assumptions about the locations of the two places were not quite correct.

Dave Hanes , http://www.astro.queensu.ca/~hanes/p014/Notes/Topic_008.html

But ... it would not matter a great deal if he had gotten an answer which was only half as large as the true circumference, or three times as big.

The critical point is that Eratosthenes recognized the nature of the problem,

found a method,

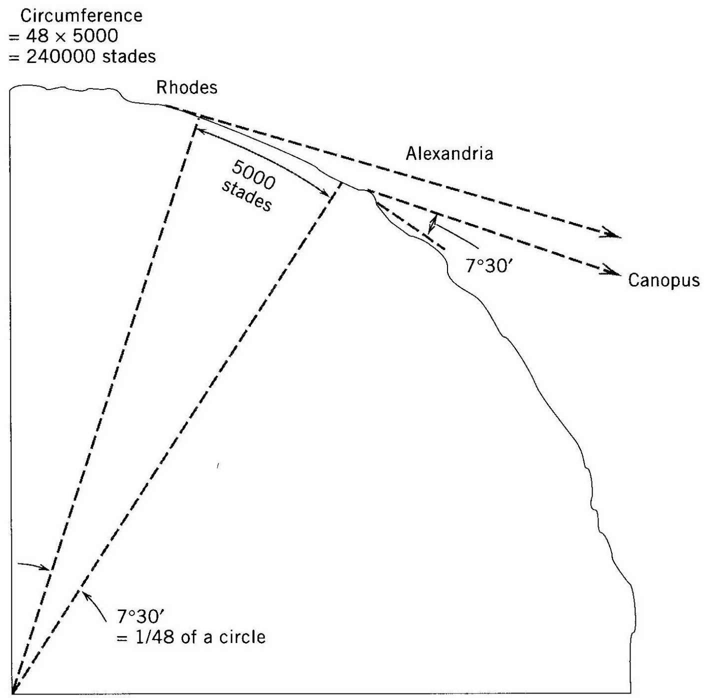
and was able to derive an answer which was *correct in spirit*

in the sense that *he correctly deduced that the Earth was an immense body which was very much larger in extent than the then-known lands of the Mediterranean basin, the home of Greek civilization at the time.*

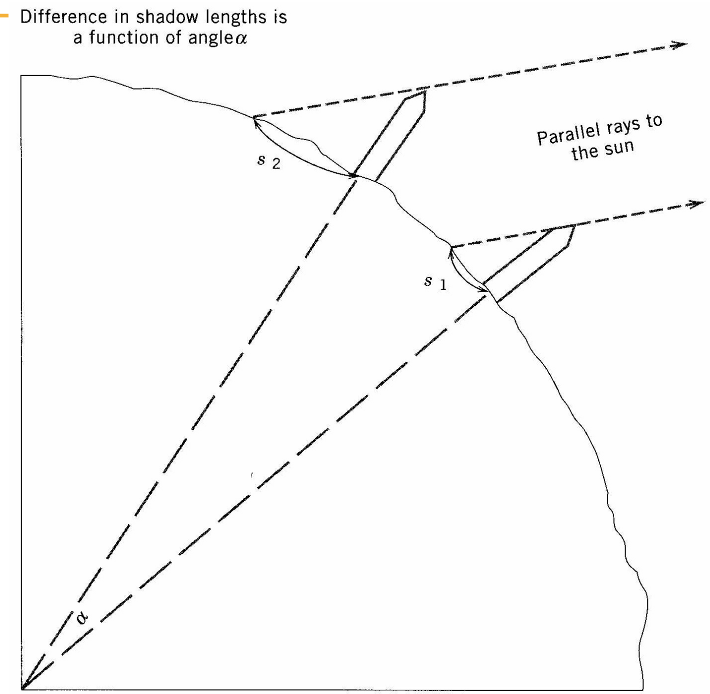
Dave Hanes , http://www.astro.queensu.ca/~hanes/p014/Notes/Topic_008.html

More Size of the Earth

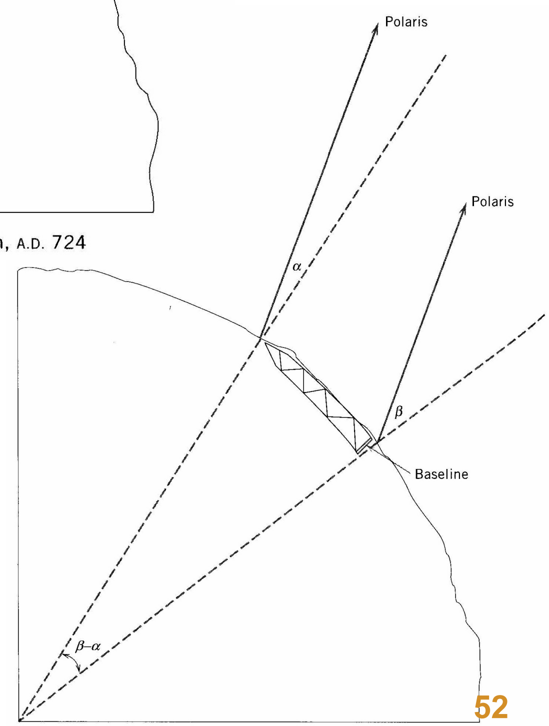
Variations on the theme –



4. Method of Poseidonius for Determining Size of Earth, 100 B.C.



5. Method of I-Hsing for Determining Size of Earth, A.D. 724



7. Use of Triangulation by Frisius (1533), Snellius (1620s)

Smith, Intro to Geodesy

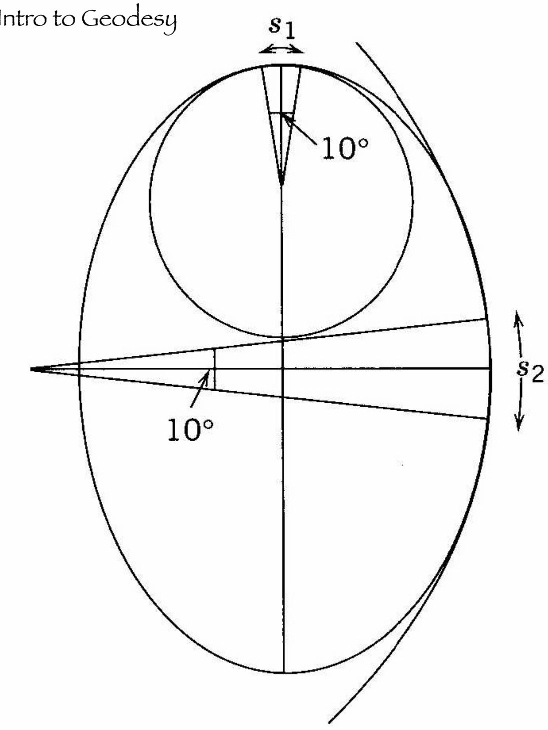
Returning to Shape of the Earth

Next advance – second order adjustment to shape

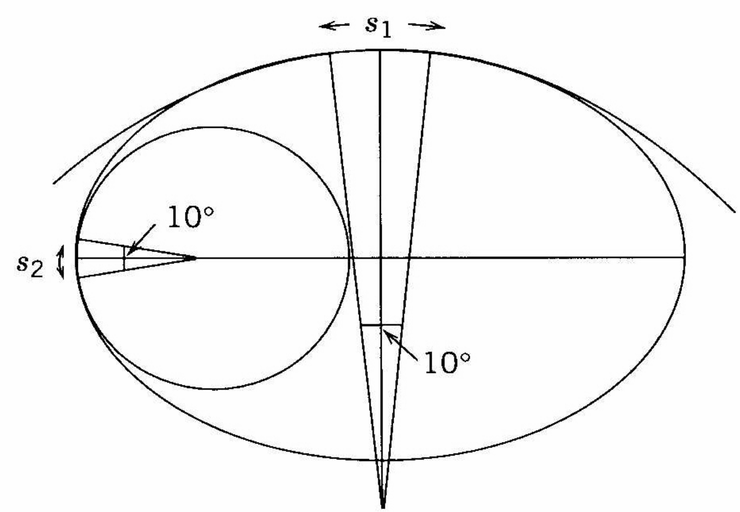
Cassini, France – based on (not so good) measurements – found earth elongated in direction of rotation axis – so a prolate spheroid.

Newton, England – based on theory, plus some (not so good) measurements – earth flattened by rotation on axis – so is oblate spheroid

Smith, Intro to Geodesy



(a) Prolate $s_2 > s_1$



(b) Oblate $s_1 > s_2$

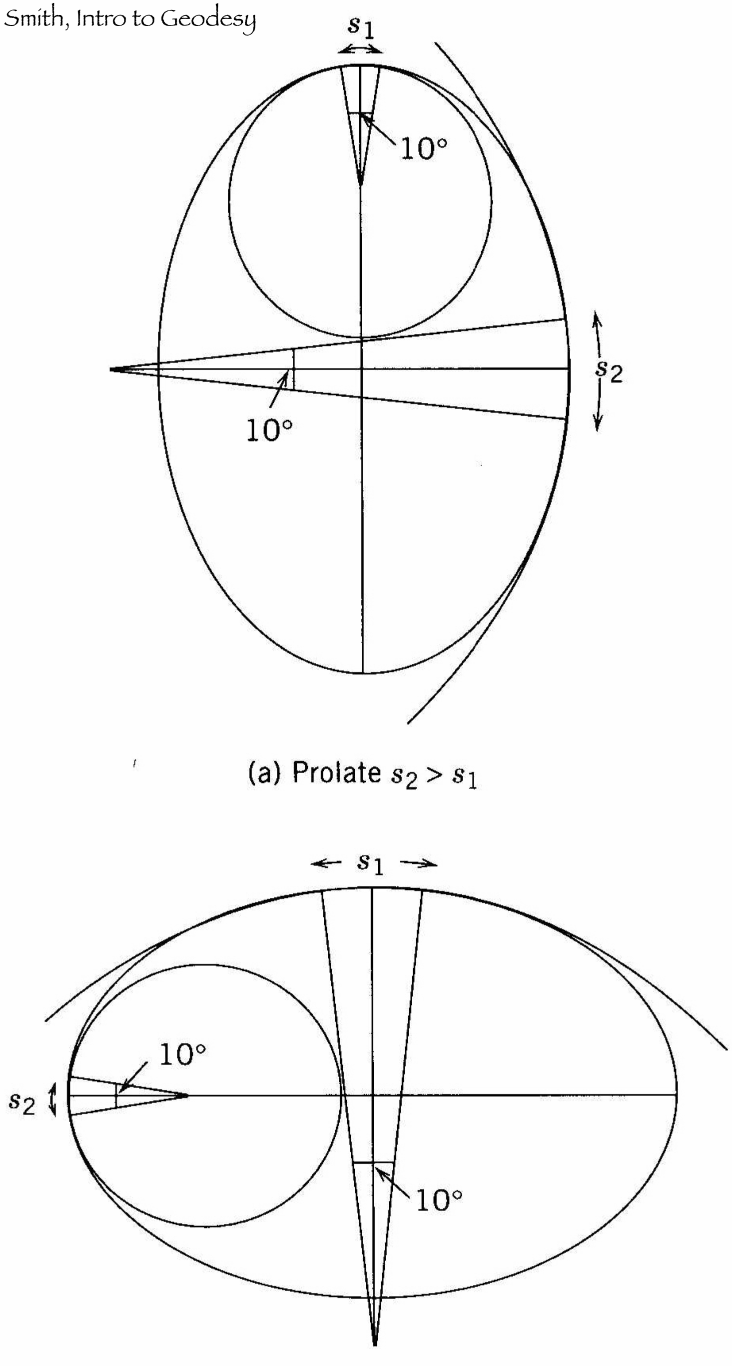
Shape of the Earth

How to solve –

Notice different length of arc for fixed angular value.

(Note – varying radii of curvature, various lines perpendicular to surface do not meet at single central point.)

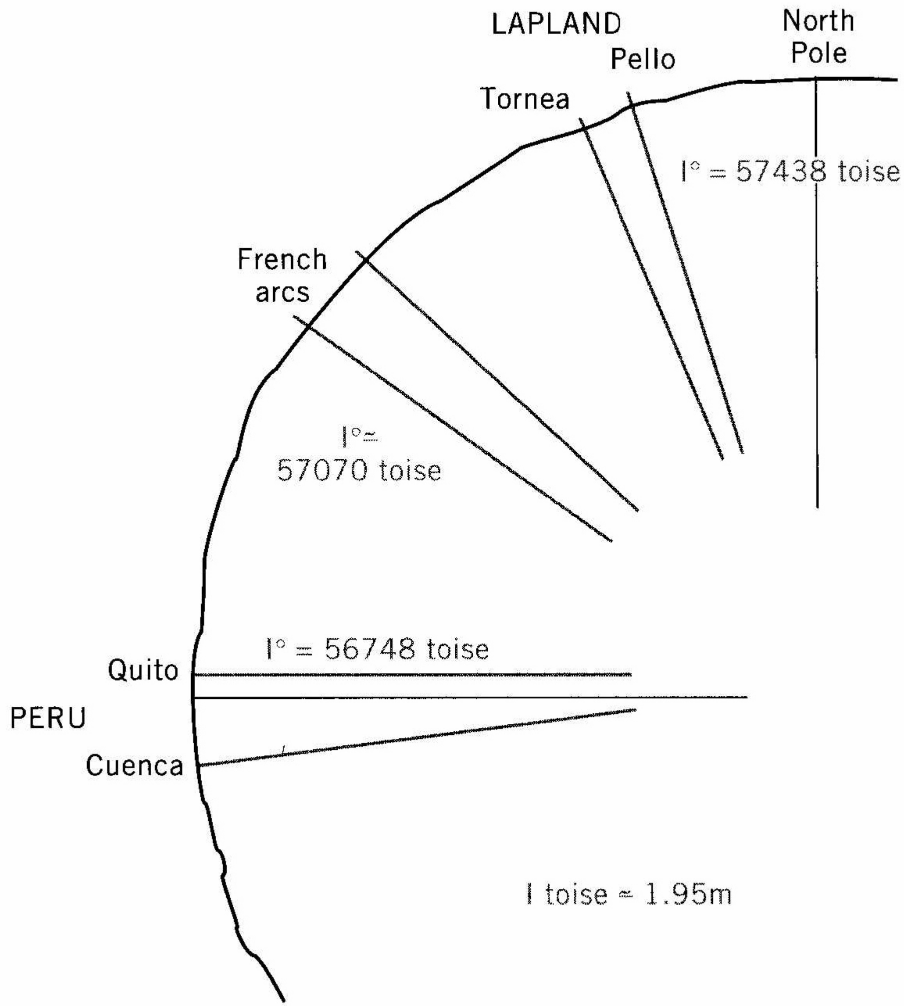
Smith, Intro to Geodesy



(b) Oblate $s_1 > s_2$

Shape of the Earth

How to solve problem –



9. Spread of 18th-Century Arcs

Smith, Intro to Geodesy

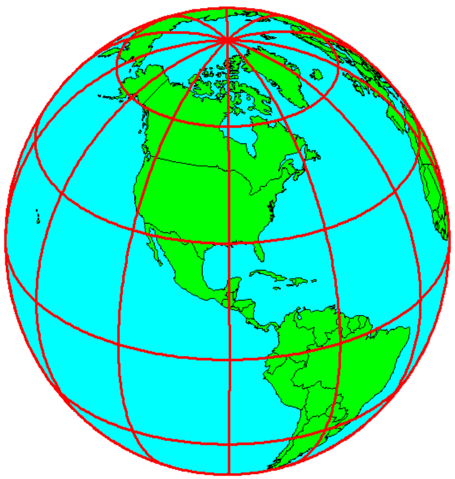
Send expeditions to as close to equator and pole as possible (where max and min arcs expected) to measure length of 1° of arc and compare.

Result – earth is oblate (pumpkin), not prolate (egg) spheroid.

Deductive experiment.

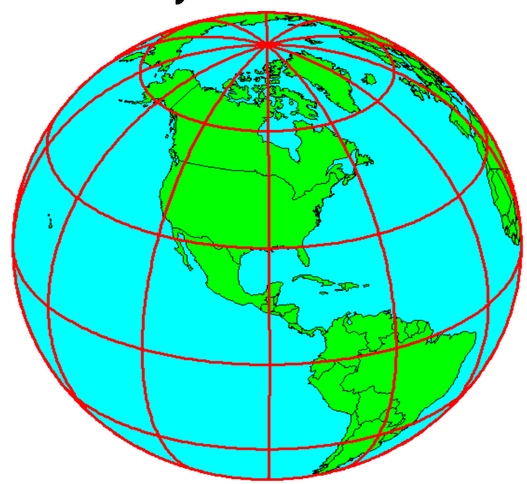
Shape of the Earth

We now think of the earth as a sphere



To a first approximation

It is actually a spheroid, slightly larger in radius at the equator than at the poles



Spheroid vs Ellipsoid:

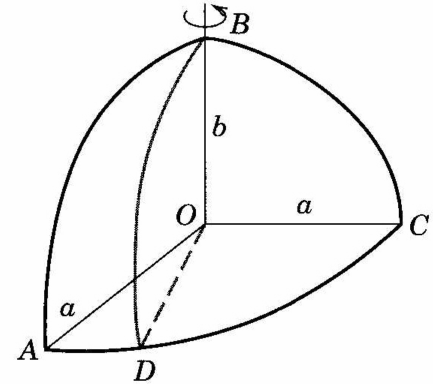
Are they the same?

Mathematics books define differently

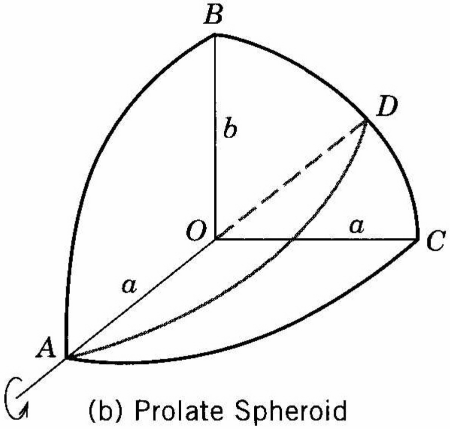
-- Spheroid – ellipse rotated around one of it's axes (circular x-secn about that axis).

-- Ellipsoid – has elliptical cross sections perpendicular to the axes.

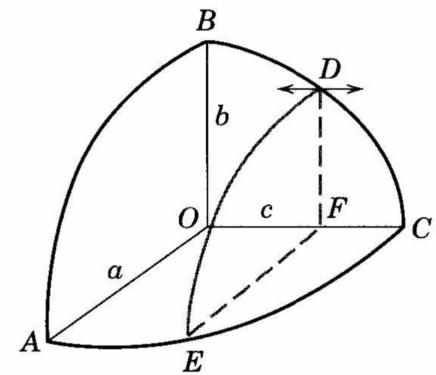
If all axes are equal it is a sphere, it two are equal it is a spheroid or ellipsoid of revolution.



(a) Oblate Spheroid



(b) Prolate Spheroid



(c) Ellipsoid

Smith, Intro to Geodesy

15. Spheroids and Ellipsoid Defined

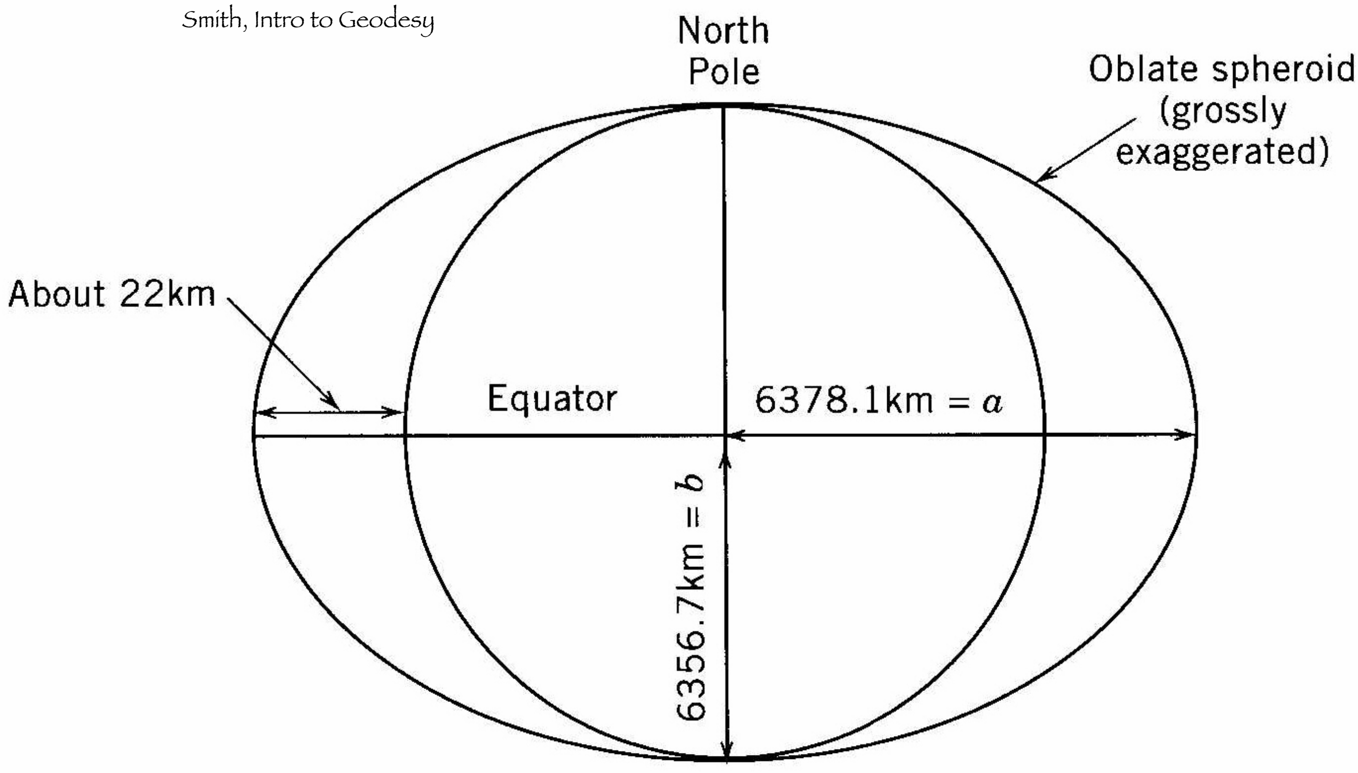
Shape of the Earth

MODERN EARTH SIZE ESTIMATE (WGS-84)

EQUATORIAL RADIUS	POLAR RADIUS
6,378,137.0 M	6,356,752.3 M

(ELLIPSOID CENTER = SPHERE'S CENTER)

Smith, Intro to Geodesy



10. Relation of Oblate Spheroid to Fitting Sphere

Spheroid, is slightly larger (<0.5%) in radius at the equator than at the poles.

How to locate/specify where you are on earth? Define "coordinate" system.

TYPES OF COORDINATE SYSTEMS

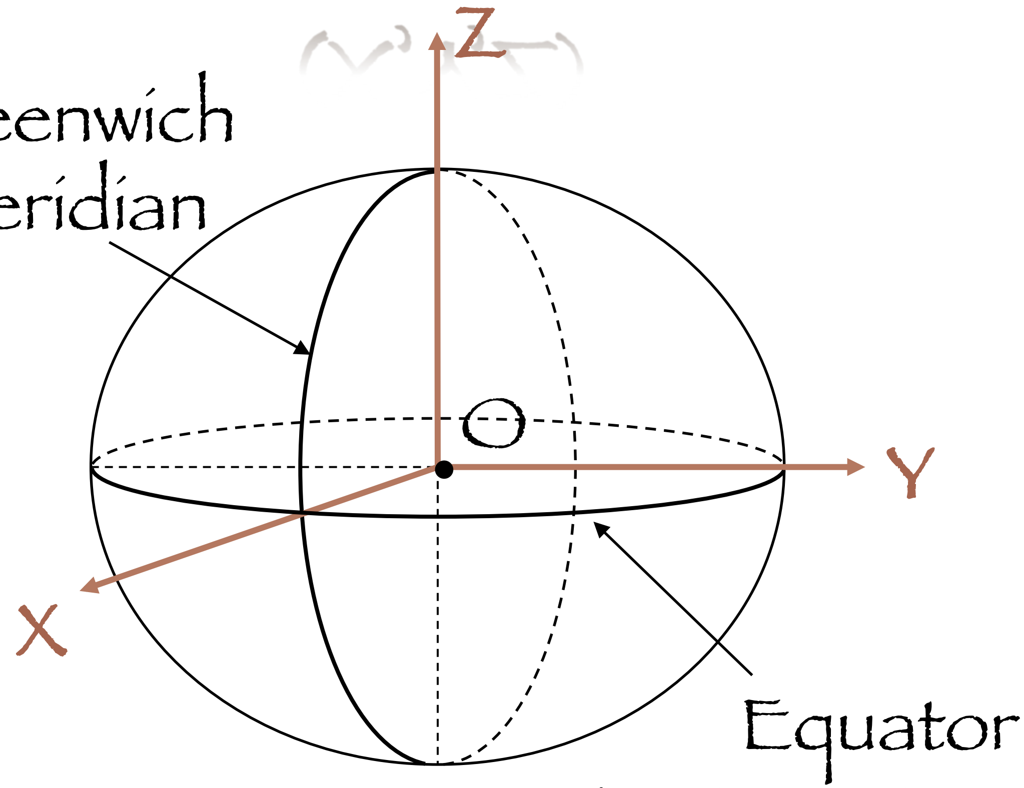
- (1) Global Cartesian coordinates (x,y,z): A system for the whole earth
- (2) Geocentric coordinates (ϕ, λ) *
- (3) Projected coordinates (x, y) on a local area of the earth's surface*

(*Ignore height for now. 2-D)

(3 is plane surveying and we'll forget about it alltogether.)

Modified from Geodesy and Map Projections, Benedict, doctorflood.rice.edu/envi512/handouts/CEVE512_Lab3.ppt

GLOBAL CARTESIAN COORDINATES (X,Y,Z)



Easiest coordinate system, everybody understands it, but extremely cumbersome and difficult to relate to other locations when translated to two dimensions on the surface. (therefore, use extensively......)

Geodesy and Map Projections, Benedict, doctorflood.rice.edu/envi512/handouts/CEVE512_Lab3.ppt

GEOCENTRIC COORDINATES (φ, λ)

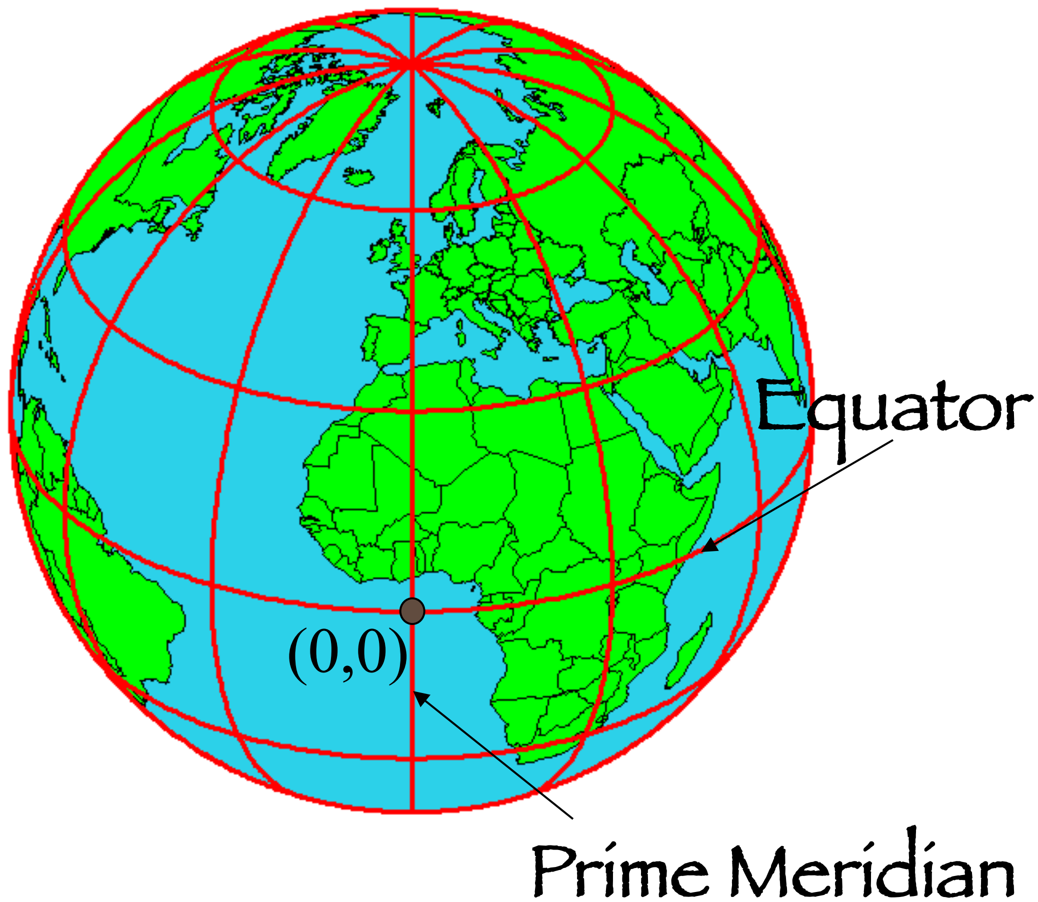
- Latitude (φ) and Longitude (λ) defined using a sphere

Geocentric Coordinates

More useful than (x,y,z), but also not very "person" friendly –

Where is

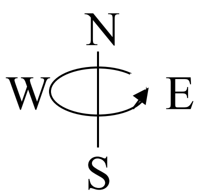
35.111263; -89.918272



Geodesy and Map Projections, Benedict, doctorflood.rice.edu/envi512/handouts/CEVE512_Lab3.ppt

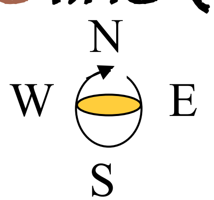
LATITUDE AND LONGITUDE

Longitude line (Meridian)

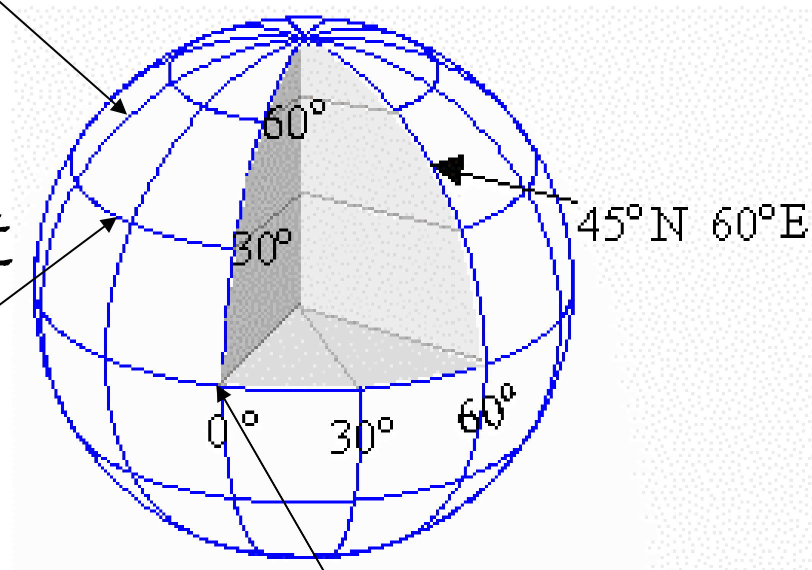


Range: 180°W – 0° – 180°E

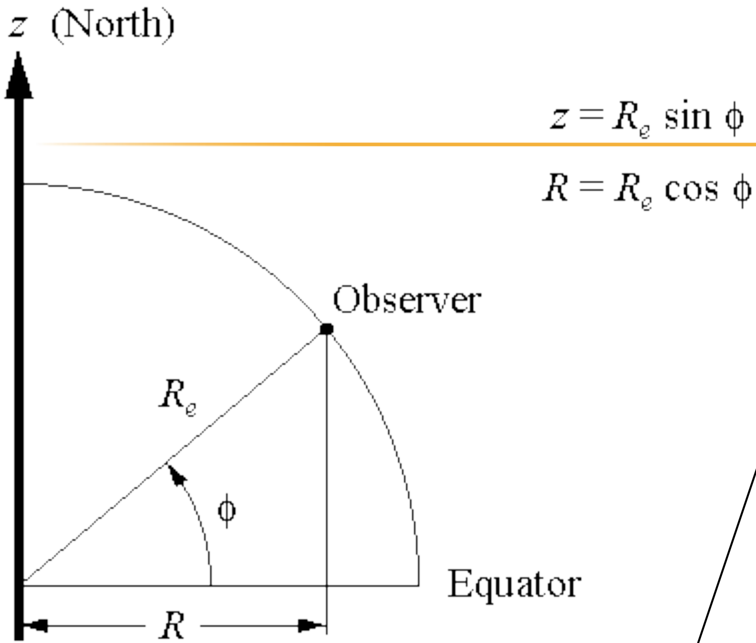
Latitude line (Parallel)



Range: 90°S – 0° – 90°N

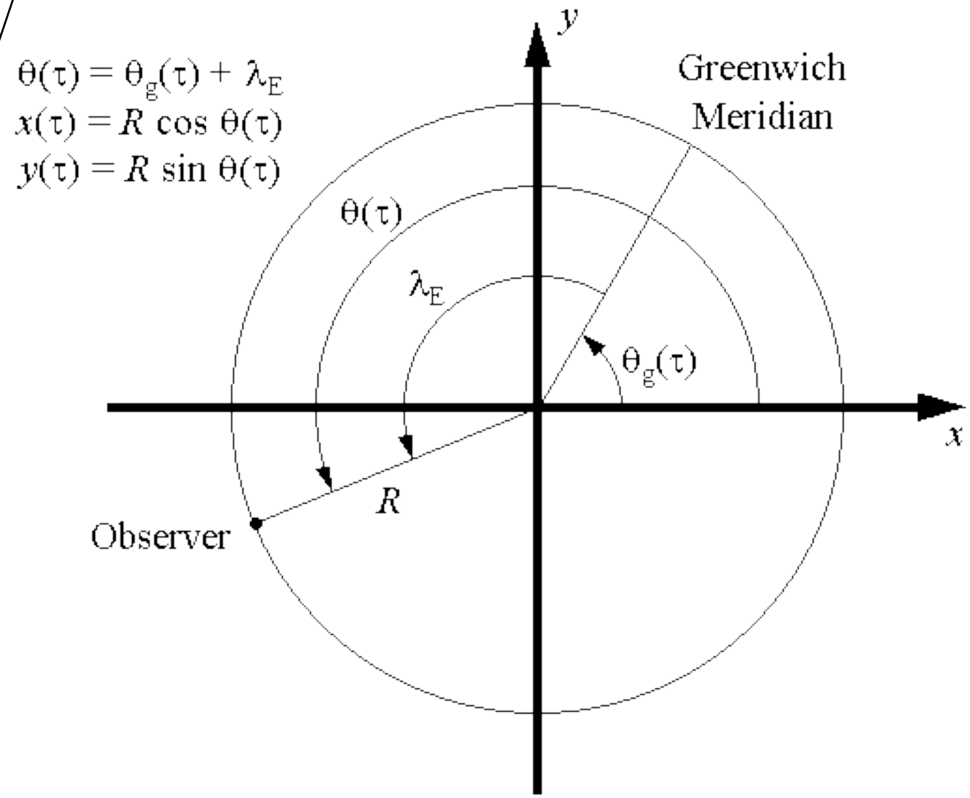


(0°N, 0°E)
Equator, Prime Meridian



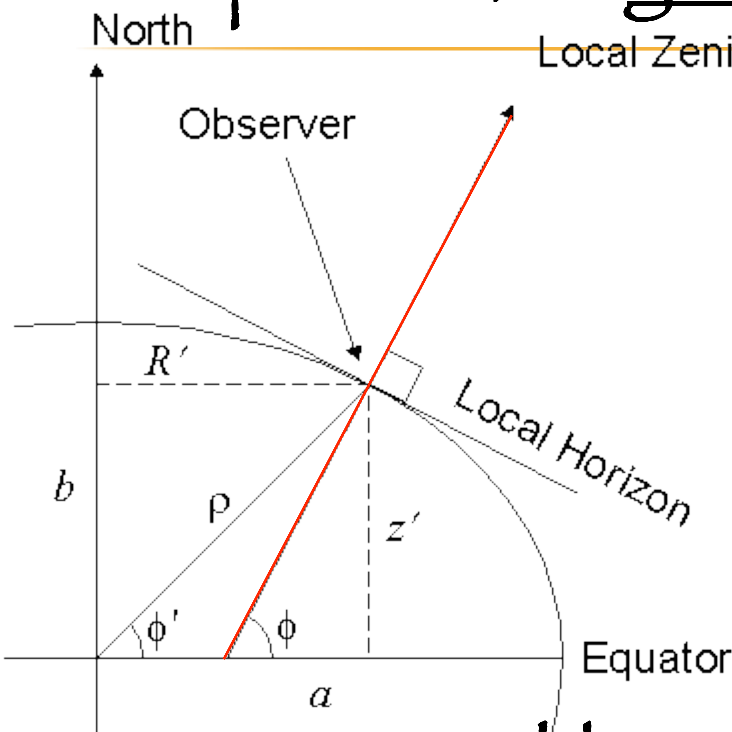
Latitude in Earth Centered Inertial (ECI) Coordinate System (assume spherical earth)

Longitude in ECI Coordinate System



Longitude measured by timing of astronomical "events" (sun crossing overhead) – needs good clocks.

Fixing latitude for ellipsoid – geocentric (regular, spherical) vs geodetic (on ellipsoid) latitude.

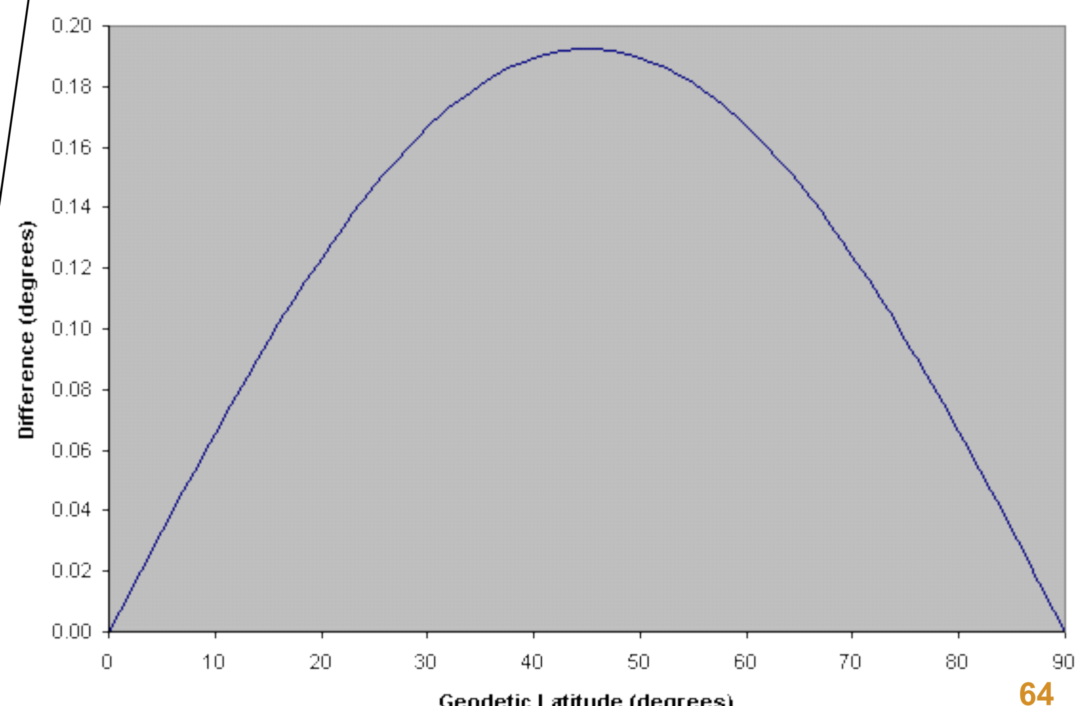


Cross section oblate earth. Measured with respect to LOCAL horizontal/vertical.

(effect exaggerated)

Geocentric vs geodetic latitude

(max difference < 0.2°)



From Kelso, Orbital Coordinate Systems, Part III, Satellite Times, Jan/Feb 1996

Returning to Shape of the Earth

Have to consider – third order adjustment to shape -- the Earth is not a perfect ellipsoid of revolution.

What to do?

Globally – can make a "best fit" ellipsoid.

Regionally/Locally ("country"/continental size) – can make a "best fit" ellipsoid.

Returning to Shape of the Earth

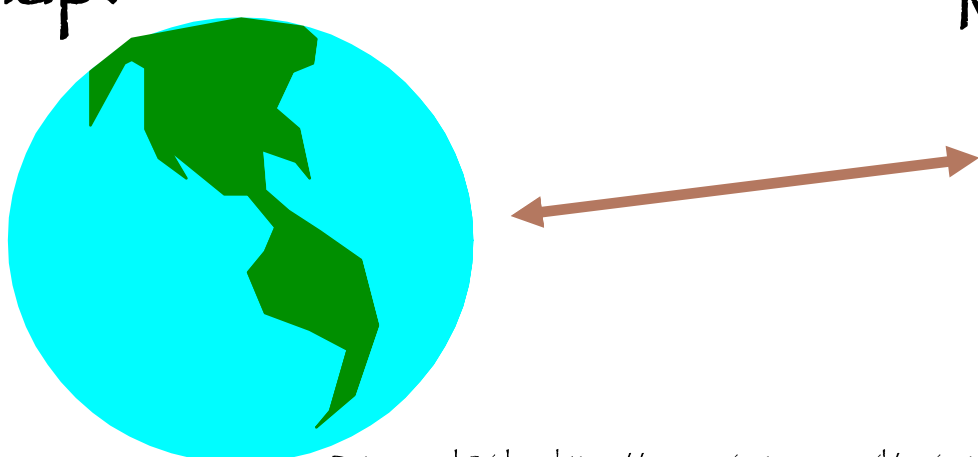
These "best fit" ellipsoids are used as a reference for the earth coordinate system are called "datums".

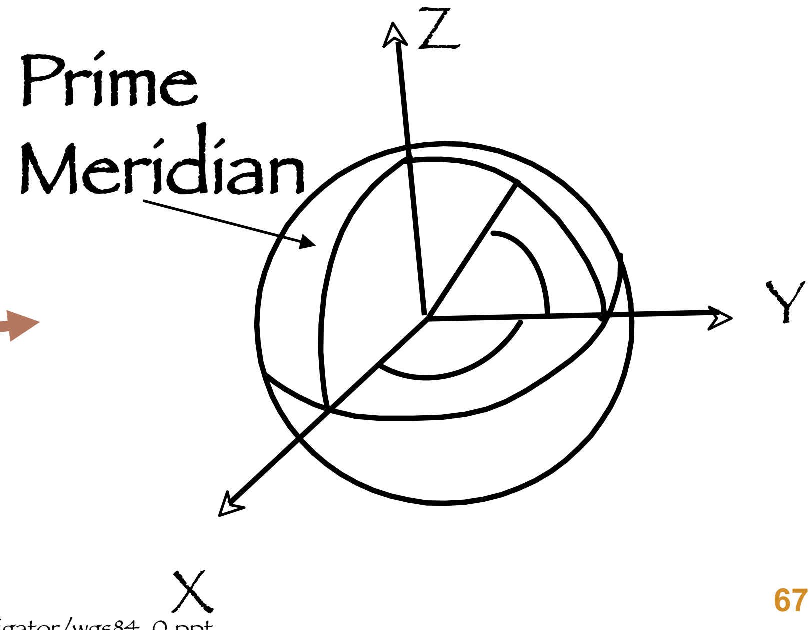
We will start with the "simple" case – horizontal reference frame/datum.

HORIZONTAL DATUM DEFINED:

At its most basic level of definition, the horizontal datum is a collection of specific points on the Earth that have been identified according to their precise northerly or southerly location (latitude) and easterly or westerly location (longitude) (National Geodetic Survey, 1986).

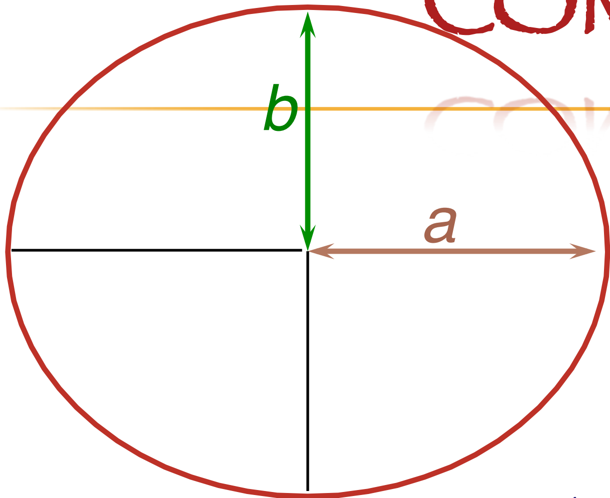
2-D location on earth or map.





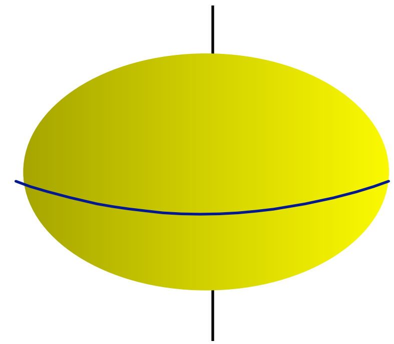
Datums and Grids -- https://www.navigator.navy.mil/navigator/wgs84_0.ppt

COMPONENTS OF DATUMS



The Ellipsoid

Rotate Ellipse about earth rotation axis:



WGS-84 Ellipsoid

Semi-major Axis: $a = 6371837$ m

Semi-minor Axis: $b = 6356752.3142$ m

Flattening Ratio: $f = (a-b)/a = 1/298.257223563$

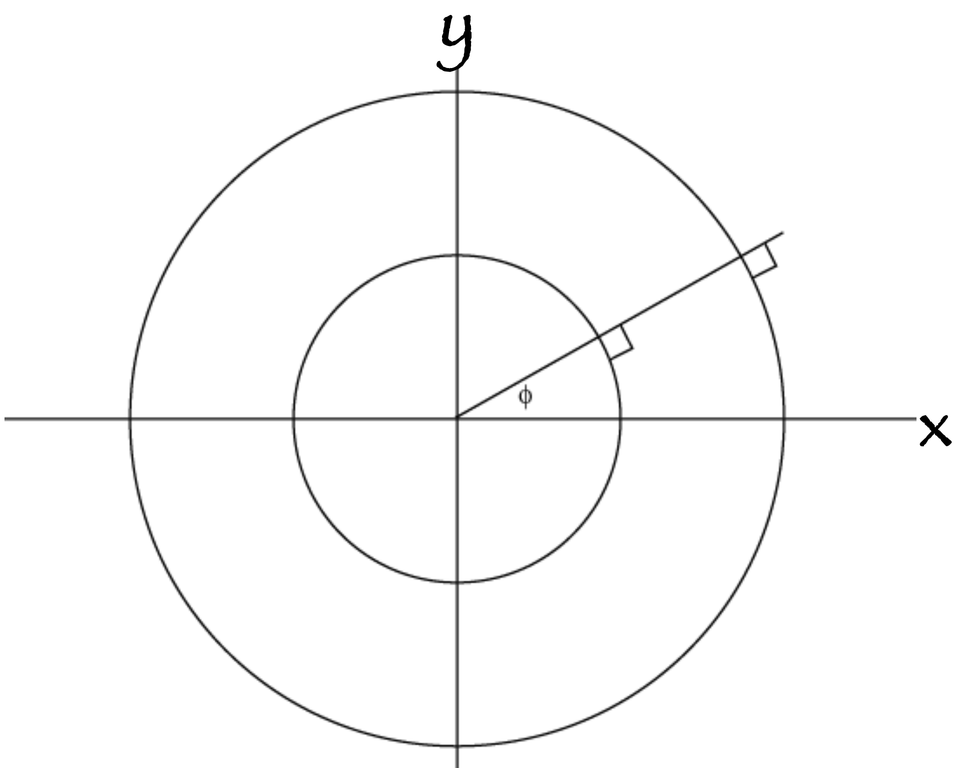
--- <u>Plus (and this extremely important part is usually forgotten) we have to say where the origin of the datum is located wrt the earth and how is it oriented.</u>

For WGS-84, the origin is the center of mass of the earth.

Some differences between spherical and ellipsoidal reference systems

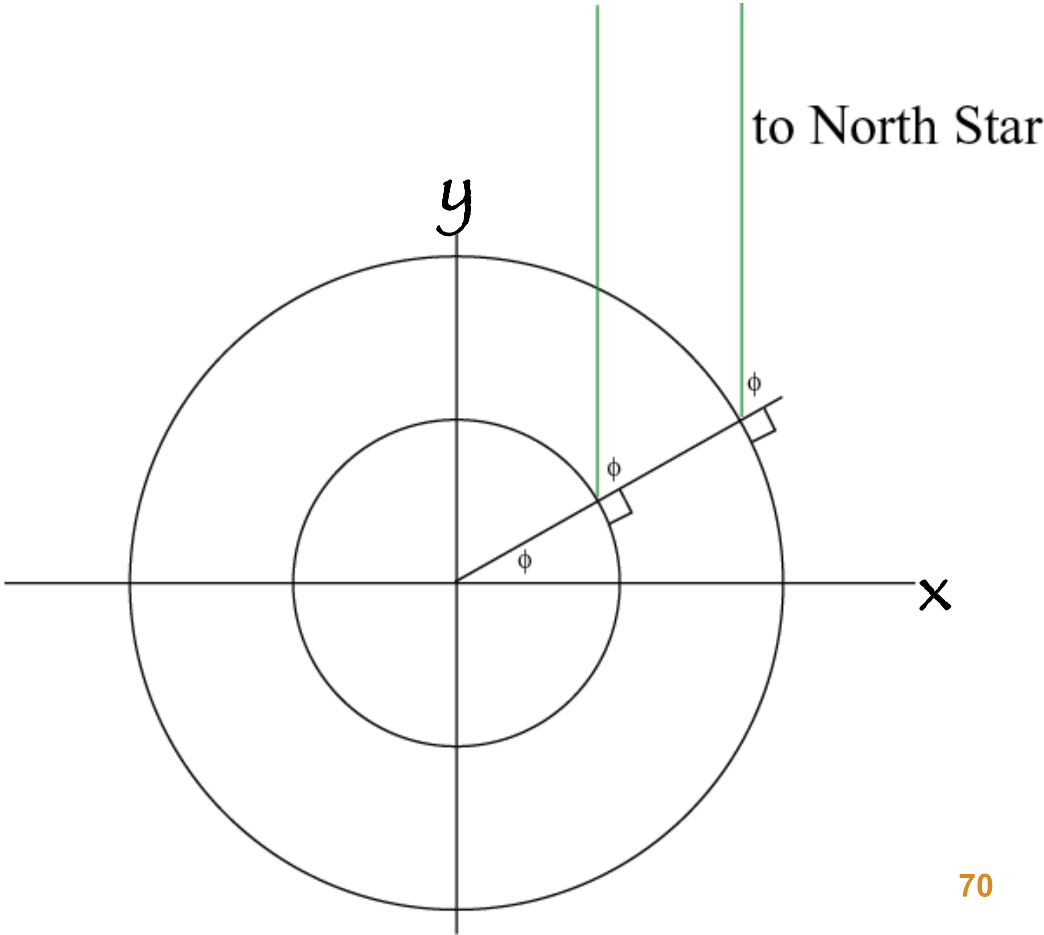
In spherical (polar) system the "size" (radius) of the reference system is immaterial (if the two systems share the same origin).

Any point (x_0, y_0) on the radial line has the same "latitude" in either system.



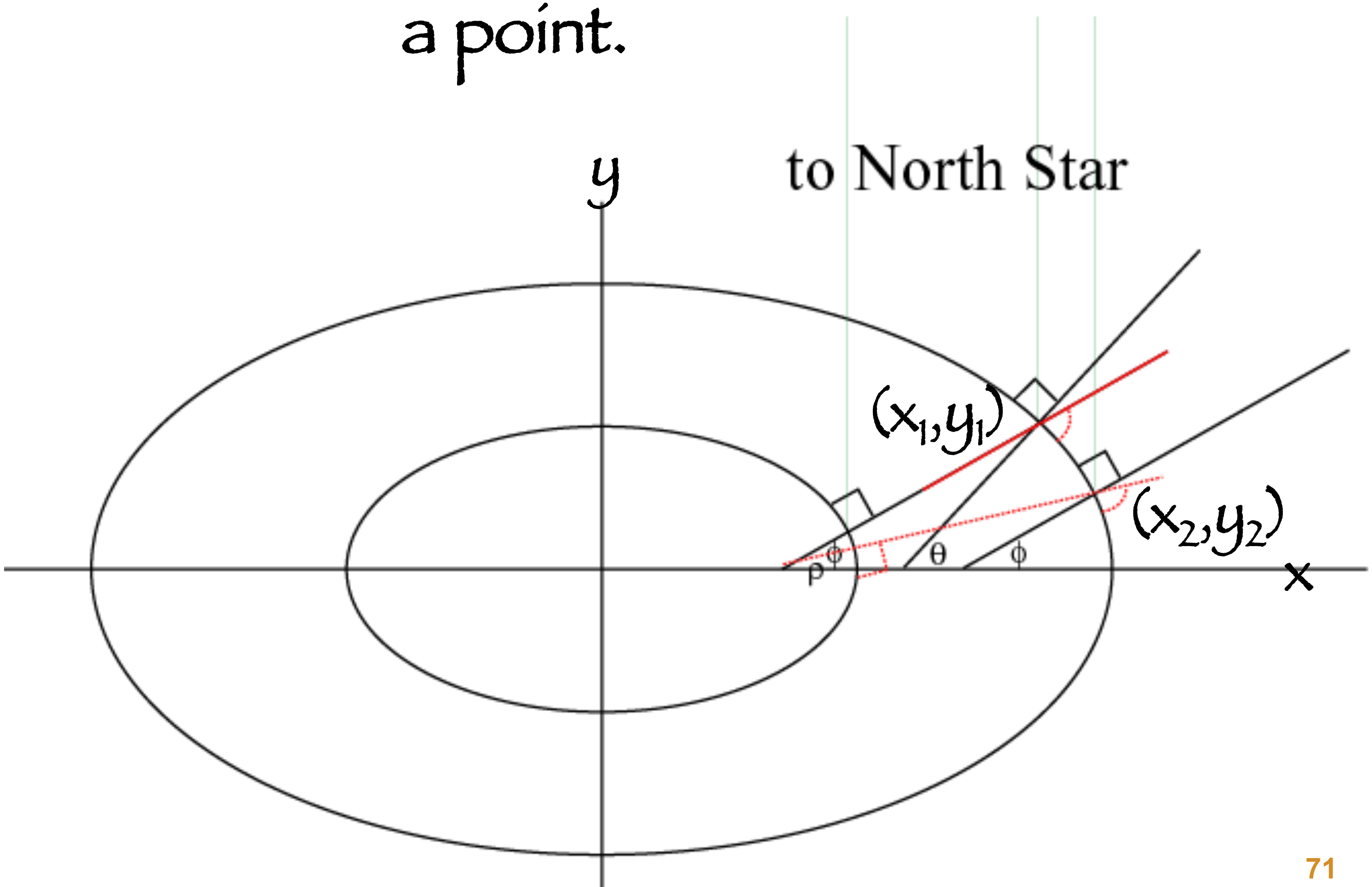
Major subtlety –

we measure where we are by determining the local "vertical", not by measuring the latitude angle at the origin.

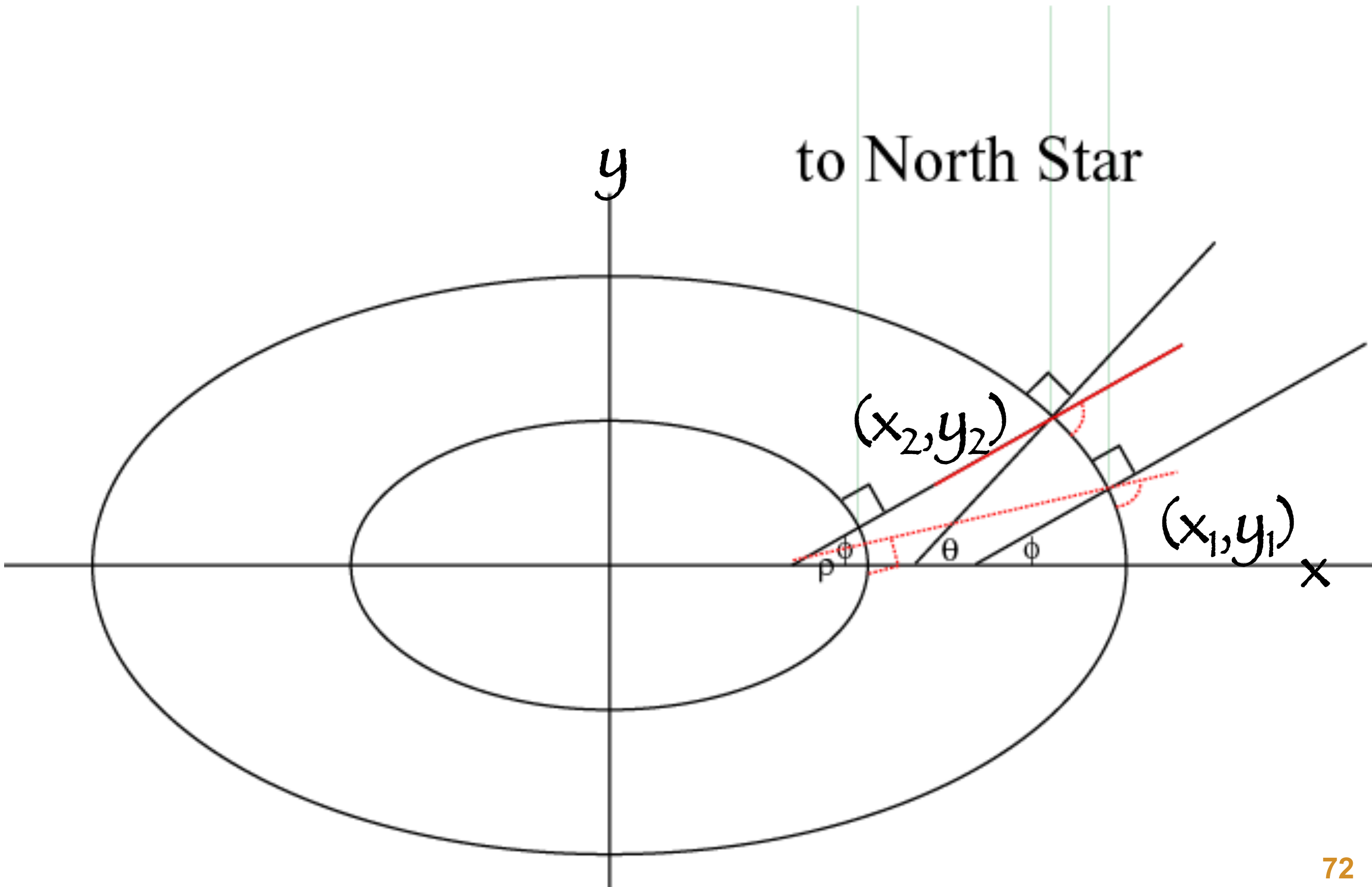


In ellipsoidial based systems, this symmetry about the origin is lost.

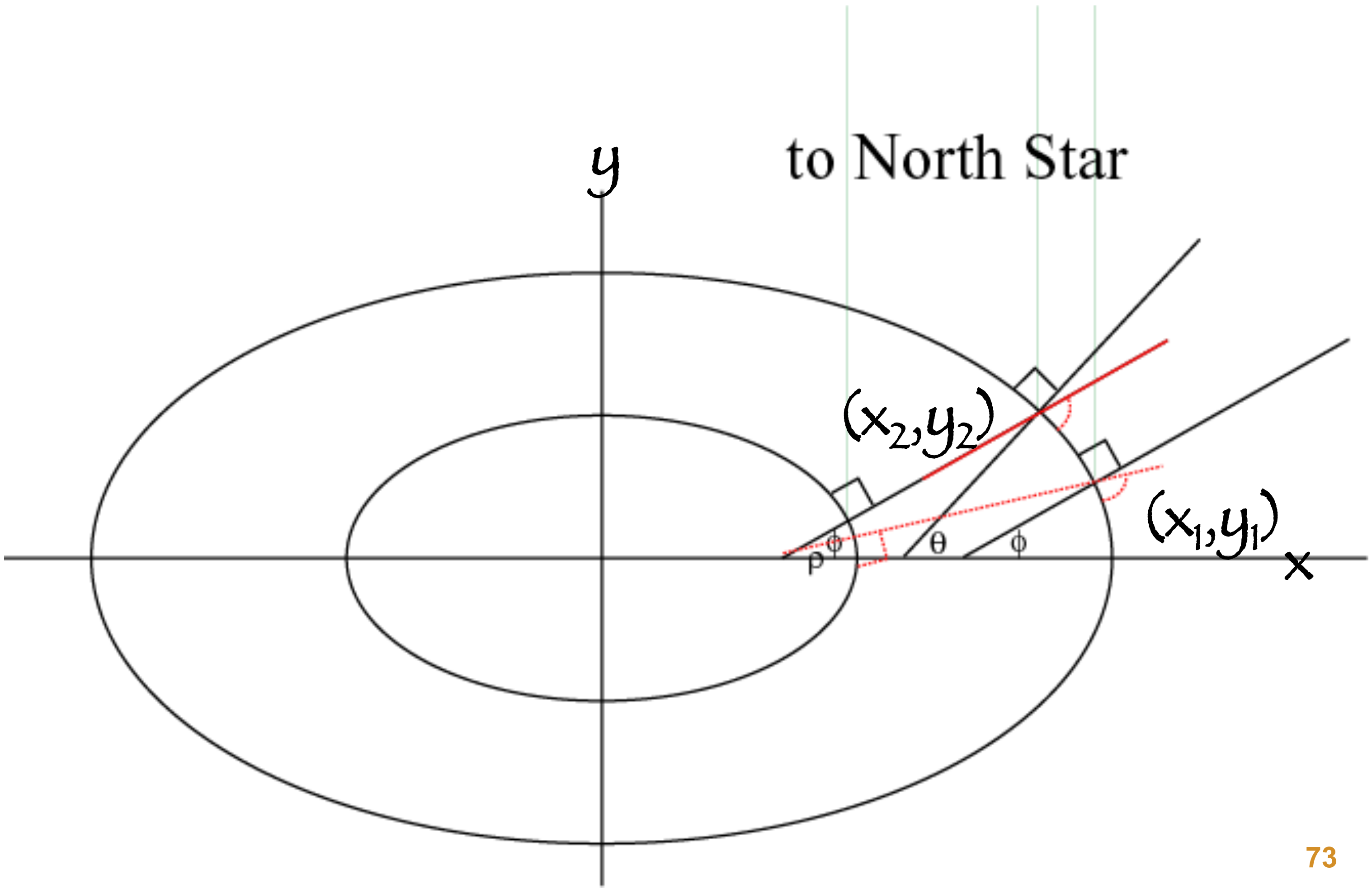
Ellipsoids with same flattening and same origin, but different size, in general <u>do not</u> give the same latitude for a point.



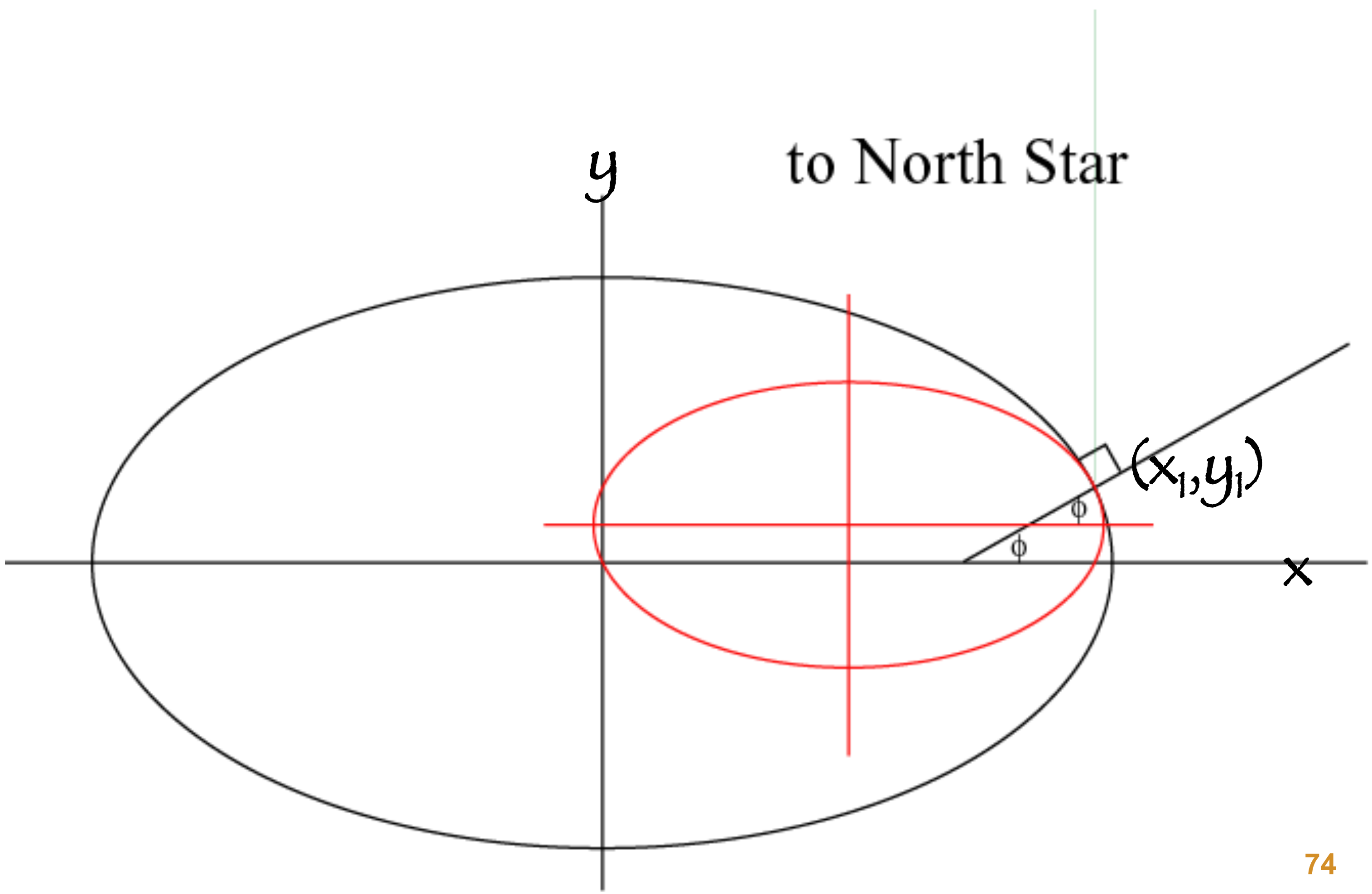
(x_1,y_1) has latitude ϕ in one system and ρ in the other, while (x_2,y_2) has latitude θ in one system and ϕ in the other.



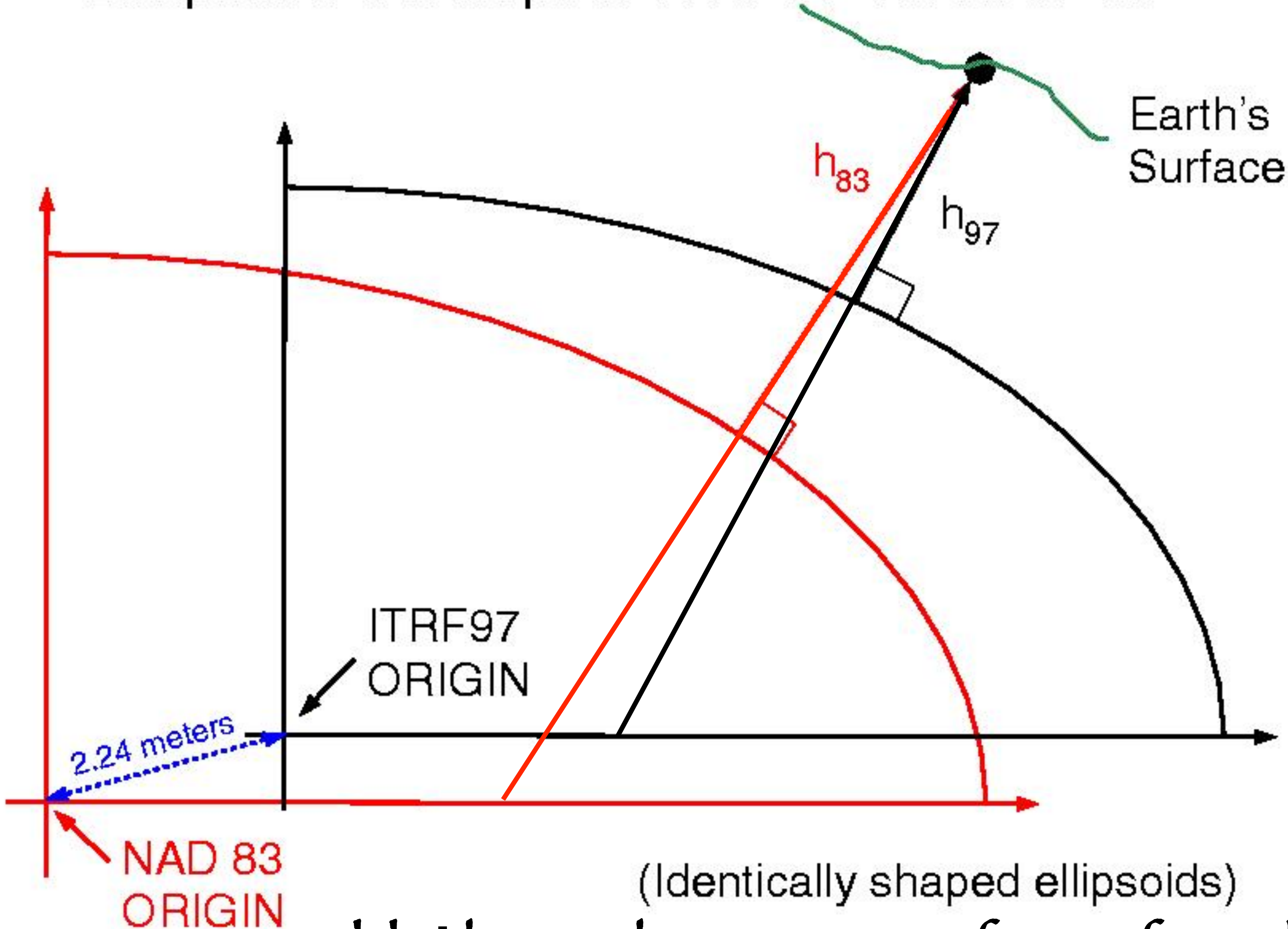
This is because we measure where we are by determining the local "vertical" on the reference ellipsoid (which may or may not pass through our "position"), not by measuring the latitude angle at the origin.



In order to produce the same "location", an ellipsoid with the same flattening parameters but a different size, will also need a different position for its center.



Simplified Concept of ITRF97 vs. NAD 83



Addn'l complication – surface of earth oftentimes not on ellipsoid.

www.evergladesplan.org/pm/recover/ recover_docs/mrt/ft_lauderdale.ppt