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GPS Locations and Costa Rican Topo Maps

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Over the past several years I have been working with Sally Horn and our U.S. and Costa Rican collaborators on several projects in Costa Rica related to paleoenvironmental research. Such research requires accurately locating geomorphic and archaeological features in the field, using GPS and the 1:50,000 scale topographic maps produced by the Instituto Geográfico Nacional. Doing so is a challenge to the uninitiated, because GPS locations (including elevation) appear to be just plain wrong when you match them to the map. A position collected on the north side of a stream plots on the south side on the map, or a position well to the east of a settlement plots in its center! From such experiences, some of our collaborators have concluded that their GPS units must be of poor quality or broken. No doubt biologists and other field researchers have found themselves similarly befuddled.

The solutions are rather technical, and many GPS users find themselves in the field without the background and tools that would be required to understand and compensate for the problem. There are some computer programs around (I know of an ArcView extension) that translate GPS data to match Costa Rican topo maps, but these don't help you orienteer while in the field. High-end GPS units are capable of being programmed to report positions that match, but most run-of-the mill ones aren't—and in any case, the current versions of Trimble products, for example, lack Costa Rican transformation parameters.

In this report I explain the nature of the problem in non-technical terms, and I provide both low-tech and high-tech solutions. The low-tech solution is a set of three maps included here that one can use to estimate the latitude offset, the longitude offset, and the elevation offset for the place you happen to be working in the field. The high-tech solution comprises complete detailed instructions, files, and transformation parameters, available online, that allow one to program either GPS desktop software or high-end GPS field units to report position and elevation coordinates accurately in several ways that match Costa Rican mapping systems (latitude-longitude, Lambert grids, the new CRTM grid, and more).

Background—the what and why of datums

Calculation of latitude and longitude (and all coordinate systems projected from latitude and longitude, such as UTM or Lambert) starts with defining a *datum*. For mathematical and mapping purposes we model the earth as a particular, precisely defined version of a simple geometric shape, a slightly squashed sphere called an *ellipsoid*, but then before you can map anything you have to tie your mathematically perfect ellipsoid

to the physical, slightly lumpy and uneven earth. The datum is the tie—its parameters define exactly how the ellipsoid is to fit inside the planet.

Traditionally, cartographers have defined datums by choosing a useful ellipsoid (or defining a new one) and then adjusting it so that the appropriate part of it fits optimally with the shape of our planet in the region which they're trying to map (while ignoring the extremely poor fit it might have someplace else). Hence, until recently most USGS topographic maps were based on the North American Datum of 1927 (NAD27), which was a particular “fit” of the Clarke 1866 ellipsoid. It was excellent for much of North America, but you wouldn't want to try to map, say, Australia or Japan using that datum, or even Alaska. Similarly, Costa Rican topographic maps up until now have been based on the Ocatepeque Datum (*Fundamental de Ocatepeque*) of 1935 (a slightly different “fit” of the same Clarke 1866 ellipsoid), named for its point of establishment in Honduras, by Sidney H. Birdseye of the U.S. Coast and Geodetic Survey (Mugnier, 1999).

The advent of modern geodesy, and then of global positioning system technology, required (and allowed) the definition of a single world-wide datum. The standard datum in current use is the World Geodetic System 1984 Datum (WGS84), a worldwide “fit” of the World Geodetic System 1984 Ellipsoid. In North America, the “fit” of the WGS84 datum is a little different than that of the NAD27 datum. As a result, the same latitude and longitude (say, 36° 00' 00.0" N, 84° 00' 00.0" W) define different points on the earth's surface, separated by meters to tens of meters (8.8 m in the example), using the two different datums. For North America, the transformation parameters are readily available and you can ask a high-end GPS to display positions using either set of coordinates.

In Costa Rica, the “fit” of the WGS84 datum is likewise a little different than that of the Ocatepeque 1935 datum. Latitude-longitude positions obtained from topo maps and from GPS tend to differ by about 260 m (Figure 1A). These are ordinary data, not geodetic-grade positions of precisely surveyed points, so errors caused by cartographic simplification, GPS accuracy, and orienteering account for most of the scatter in the cluster, but the large displacement of the cluster from the origin represents the differences between the two datums.

Datum transformation formulae for Costa Rica are less readily available, and produce varied results. Researchers at the Escuela de Topografía, Catastro y Geodesia at the Universidad Nacional de Costa Rica (UNA; see <http://www.una.ac.cr/topo/>) are engaged in an extensive project of resurveying the country's geodetic network using GPS technology, but at this writing that work is in progress. The Registro Nacional web pages (<http://196.40.22.10/> then click on Catastro Nacional) include two *mathematically* exact seven-parameter transformations—but these appear to be derived directly from the original technical datum definitions in Honduras rather than from an examination of the surveyed triangulation grid. Transformations using the gravimetric definition (*modelo baricéntrico*) tend to yield solutions with errors on the order of 200 m (Figure 1B). Transformations using the celestial definition (*modelo no baricéntrico*) work much better, yielding solutions with errors on the order of 40 m (Figure 1C).

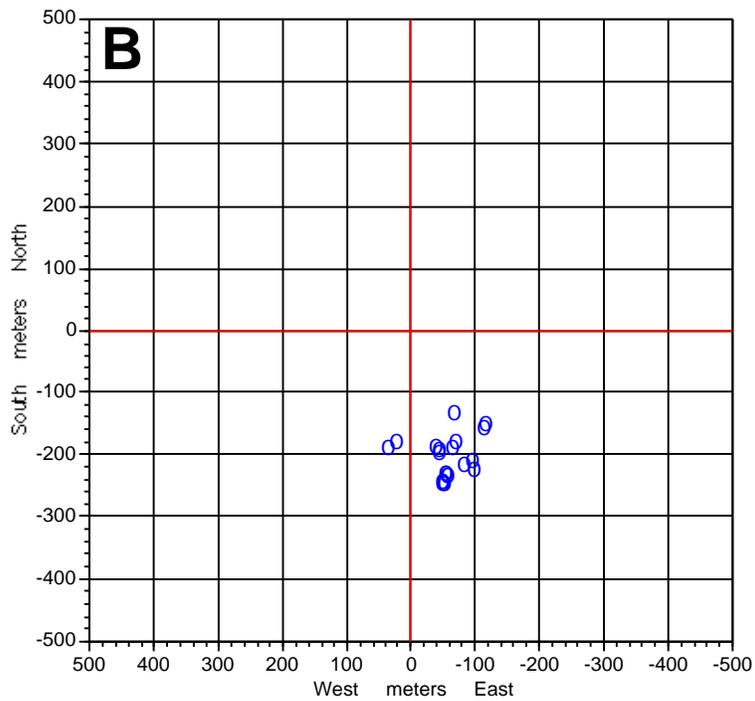
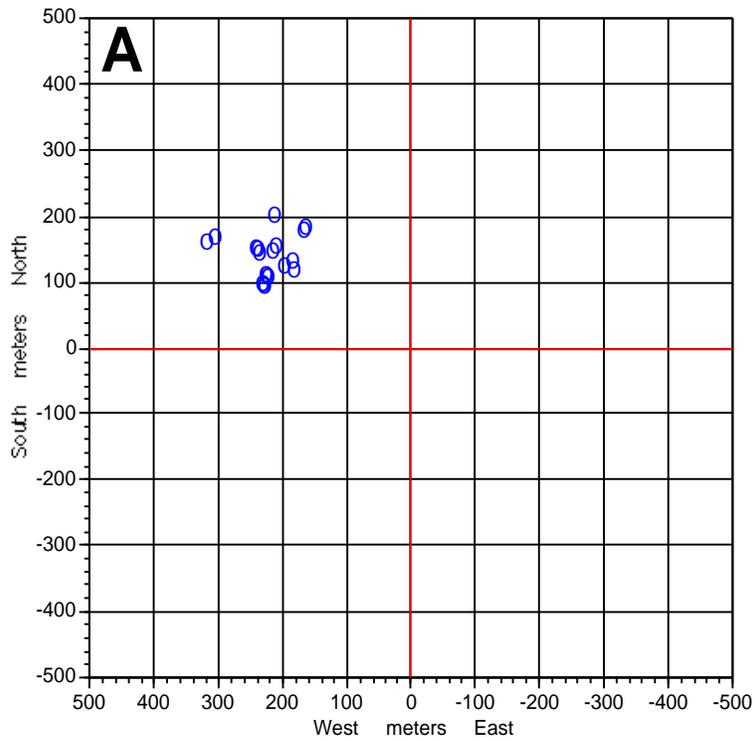


Figure 1. **A.** Typical results of plotting locations calculated from topo map relative to GPS positions of the same features. The origin (center of graph) represents all GPS positions. **B.** After transformation using *modelo baricéntrico*. [continues overleaf]

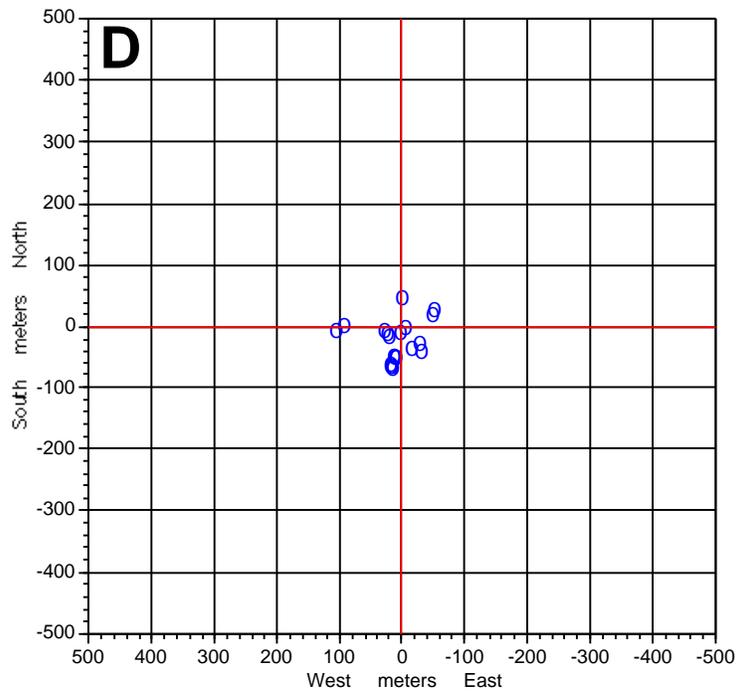
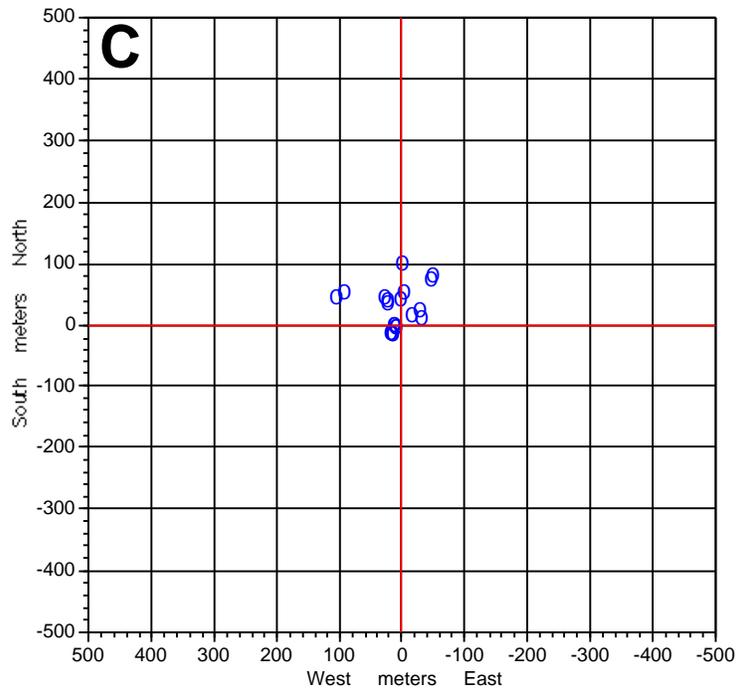


Figure 1, cont. C. Same data after transformation using *modelo no baricéntrico*.
D. After transformation using Molodensky parameters of Stentz. Points closest to origin are benchmarks; those most distant (left) are points along shoreline of ephemeral lake. Others are road intersections, bridges over rivers, hilltops.

I've had the best results with a Molodensky transformation that is embedded in an ArcView extension which Mauricio Castillo Núñez of OTS sent to us. The program, developed by the Departamento de Geografía of UNA, attributes the Molodensky parameters to a G. Stentz of the U.S. National Imagery and Mapping Agency (NIMA). Any solution errors fall well within the scatter of the sample (Figure 1D). The program notes claim an accuracy of about ± 10 m, which is reasonable considering the fact that better-mapped locations such as bench marks appear closest to the origin in Figure 1D.

For most practical purposes, either Stentz's transformation or the Registro Nacional's modelo no baricéntrico should suffice. A differentially corrected GPS position (± 2 m) or even a five-minute mean of uncorrected solutions (typically ± 6 m) combined with ± 10 m transformation error define location circles of about 0.5 mm and 0.6 mm respectively, well within the cartographic precision of the topo maps for most classes of features. In the worst case, ± 15 m instantaneous, uncorrected GPS accuracy and ± 40 m transformation error define a location circle 110 meters across—only 2.2 mm at map scale.

Low-tech solution: How to work between GPS and map coordinates by hand

Figures 2 and 3 are designed to let you move between WGS84 latitude-longitude and Ocatepeque 1935 latitude-longitude fairly accurately without a computer. The differences between one datum and the other vary geographically, so I've plotted the latitude offset (Figure 2) and the longitude offset (Figure 3) as contours on a map of the Costa Rica region. Offsets are in arc-seconds.

Costa Rican topos are typically 10 minutes of latitude north-to-south and 15 minutes of longitude east-to-west. In the figures, the light lines in the background correspond to map edges. For example, the Belén quadrangle ($10^{\circ} 20' - 10^{\circ} 30' \text{ N}$, $85^{\circ} 30' - 85^{\circ} 45' \text{ W}$) is represented by the small rectangle second from the left and tenth from the top. Perhaps you want to plot on the map a GPS location that you acquired in the town of Los Planes, near the center of the Belén sheet. Say your GPS position is $10^{\circ} 25' 8.73'' \text{ N}$, $85^{\circ} 37' 26.85'' \text{ W}$, with an elevation of 76.4 meters

In Figure 2 the center of the Belén sheet falls between the 5.4 and 5.5 contours, and if I interpolate I get about 5.41 arc-seconds. You add 5.41 to your GPS latitude to obtain $10^{\circ} 25' 14.14'' \text{ N}$ in the Ocatepeque datum. For most purposes that much precision is overkill, since in Costa Rica a hundredth of a second of latitude is only about 31 cm on the ground—or 6 μm on the map! In any case, I also get $10^{\circ} 25' 14.14'' \text{ N}$ using Stentz's transformation on the computer.

In Figure 3 the center of the Belén sheet falls between the 6.95 and 7.00 contours, at about 6.96 arc-seconds. Adding 6.95 to my GPS longitude yields $85^{\circ} 37' 33.81'' \text{ W}$ in the Ocatepeque datum. Again, in Costa Rica a hundredth of an arc second of longitude is about 30 cm on the ground, and again I get the same answer using the computer.

Elevation is a tougher problem. In part, GPS technology is inherently worse at judging altitude than latitude or longitude, simply because the satellites are all overhead,

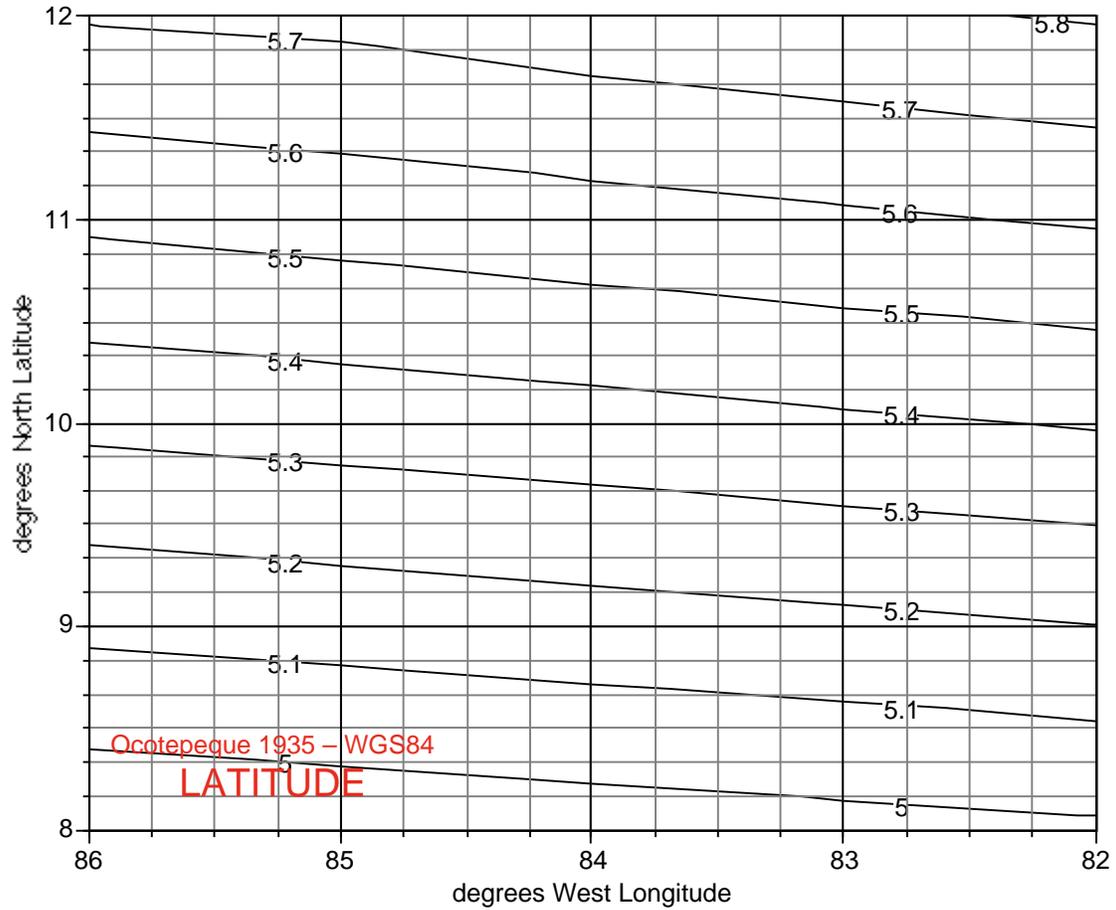


Figure 2. Map of LATITUDE offset in arc-seconds. Faint lines show pattern of 1:50000 scale topo sheet boundaries. At your location, interpolate between contours to find value (*Isla del Coco*: use 4.39). To estimate Ocotepaque 1935 latitude, add value to WGS84 latitude. To estimate WGS84, subtract from Ocotepaque. To approximate meters as mapped (Lambert grid), multiply value by 30.72.

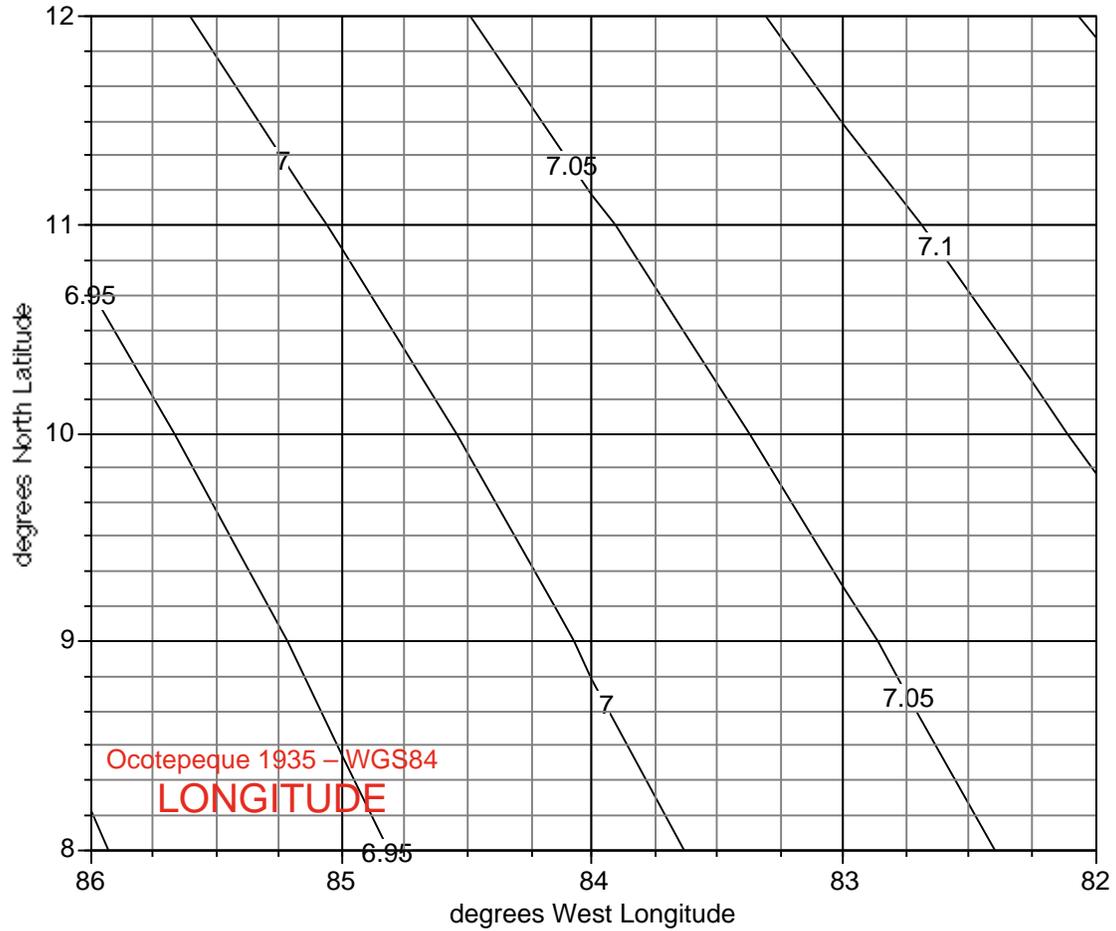


Figure 3. Map of LONGITUDE offset in arc-seconds. Faint lines show pattern of 1:50000 scale topo sheet boundaries. At your location, interpolate between contours to find value (*Isla del Coco*: use 6.81). To estimate Ocotepeque 1935 longitude, add value to WGS84 longitude. To estimate WGS84, subtract from Ocotepeque. To approximate meters as mapped (Lambert grid), multiply value by 30.47.

so it's like trying to triangulate your location by sighting to objects that are all on one side of you. The main problem, however, is that sea level isn't flat, because Earth's gravitational field varies a little from place to place. Out in the ocean, places with more gravity attract more water, and sea level there is a little higher as a consequence. On land, surveyors' levels similarly adjust a little in response to local differences in gravity. Technically, sea level is an *undulating* surface where gravity is everywhere exactly equal. GPS technology, on the other hand, can tell you precisely where you are in relation to the center of the earth, but neither the satellites nor your GPS care much about gravity and how the sea level equal-gravity surface (or *geoid surface*) might be undulating near where you are.

In other words, when it comes to elevation, GPS and maps are speaking different languages. Topographic maps only tell you the vertical distance from where sea level *would* be if the sea extended beneath you, whereas GPS by itself can only tell you your height above the ellipsoid surface (because the ellipsoid is defined mathematically, relative to the center of the earth). To translate between the two, we use *geoid models*, essentially big computer lookup tables of measured geoid-ellipsoid differences, that allow GPS or computer software to interpolate between measured points so as to *estimate* the difference at arbitrary locations. The estimate is only as good as the geoid model used, but Geoid models are continually improving.

Figure 4 is similar to Figures 2 and 3, but the contours represent approximate geoid-ellipsoid elevation differences in the Costa Rica region (WGS84 HAE; if your GPS only reports NAD27 [Central America] HAE, use Figure 5). The ellipsoid is the WGS-1984 ellipsoid used with the WGS84 datum, and the geoid model is the best that currently covers all of Costa Rica, a global model called EGM96 (based on the Earth Gravitational Model of 1996). Its resolution is 15' x 15' of arc, but Figure 4 is simplified. What's immediately evident is that sea level is everywhere lower than the WGS-1984 ellipsoid, including a 15-meter-deep trough coincident with the Cordillera de Talamanca (which probably indicates that the Cordillera has deep granitic roots that are gravitationally weak).

The GPS elevation at your position in Los Planes on the Belén quadrangle is most likely (check your GPS documentation) a *height above ellipsoid* (HAE) value of 76.4 meters, and the ellipsoid in question is likely the WGS-1984 ellipsoid. In Figure 5, the center of the Belén quadrangle falls between the 9-meter and 10-meter contours (smooth the contours mentally), at about 9.2 meters. To estimate elevation above sea level, subtract 9.2 from 76.4 to get 67.2 meters. As above, such precision is usually meaningless—the number is only as good as the vertical accuracy of your GPS position combined with the quality and resolution of the geoid model. On the other hand, elevations on the topo map are only as good as the surveying that defined them, and contour lines at best are only intended to be accurate to half their interval, or $\pm 10\text{m}$ on most Costa Rican maps. On the computer, I get 66.9 m using the EGM96 model, and 66.5 m using the more recent and detailed Caribbean 1997 model (which only covers part of Costa Rica).

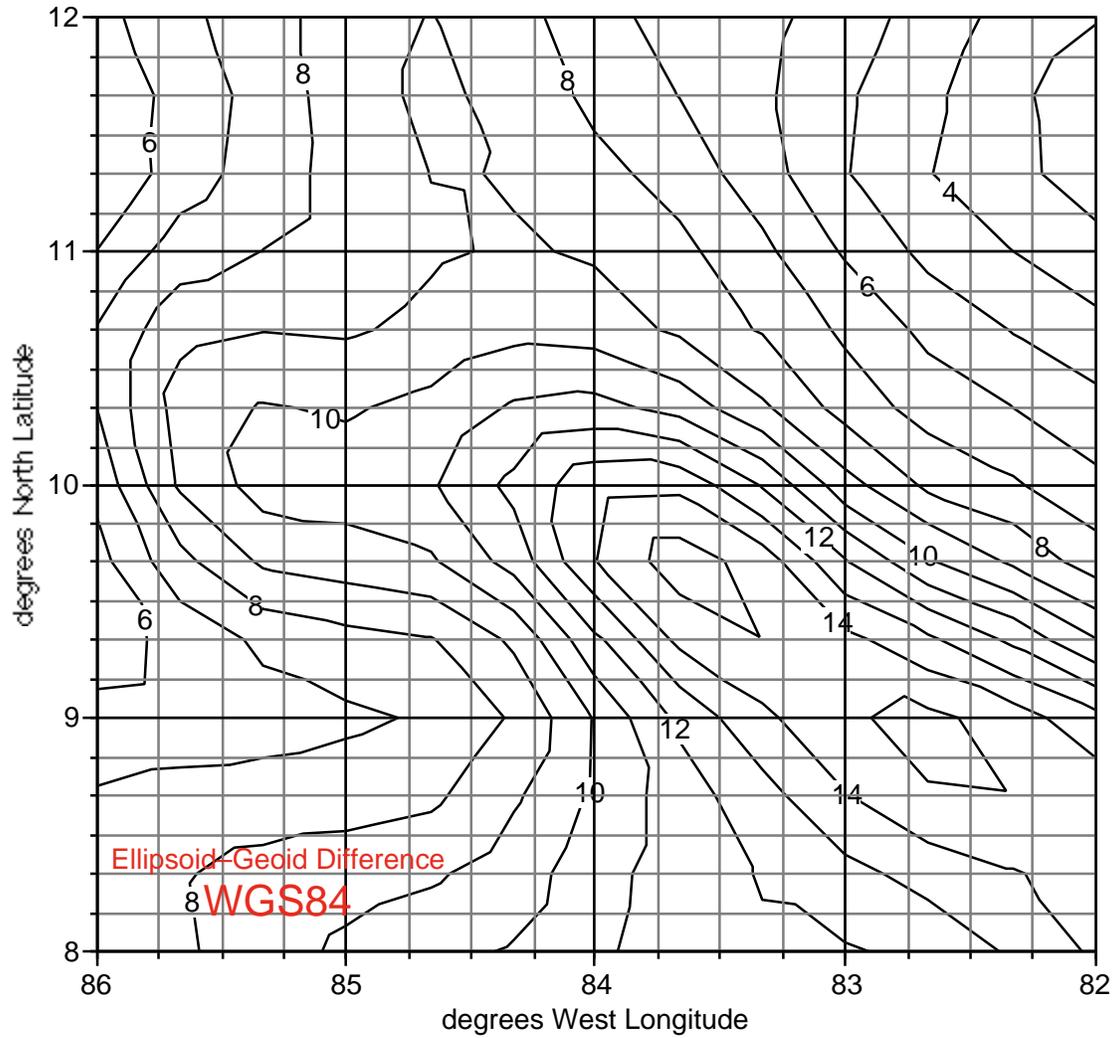


Figure 4. Map of WGS84 ELEVATION difference in meters (EGM96 15' data). Faint lines show pattern of 1:50000 scale topo sheet boundaries. At your location, interpolate between contours to find value (*Isla del Coco: use 4*). To estimate map elevation, subtract value from WGS84 HAE. To estimate WGS84 HAE, add to map elevation.

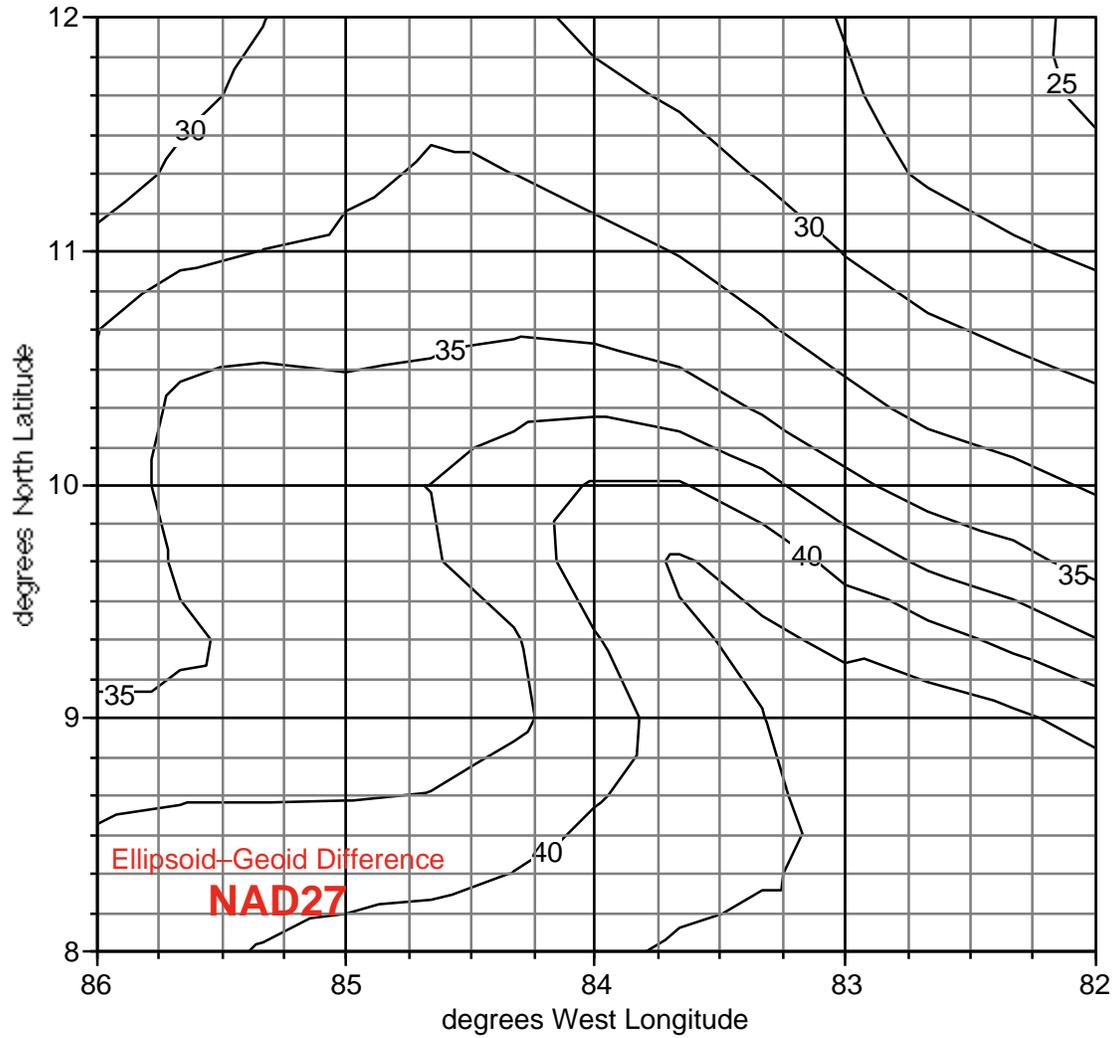


Figure 5. Map of NAD27 (Central America) ELEVATION difference in meters (EGM96 15' data). Faint lines show pattern of 1:50000 scale topo sheet boundaries. At your location, interpolate between contours to find value (*Isla del Coco: use 42*). To estimate map elevation, subtract value from NAD27 HAE. To estimate NAD27 HAE, add to map elevation.

High-tech solution: Making your GPS speak Ocotepaquean (and real elevation)

Many versions of GPS desktop support software allow you to enter transformation parameters so that it can automatically display and export GPS data in arbitrary coordinate systems and datums, and elevations estimated using a geoid model. Many GPS field units allow you to upload such parameters (and small geoid models) so that they can automatically display positions and elevations that match your topo map. In this section I explain how to do this for common Costa Rican datums and coordinate systems. I include specific instructions that pertain to users of Trimble GPS units and Trimble GPS-support computer software, called Pathfinder Office (version 2.80), but users of other software packages should be able to easily follow along with your manual, because the steps are necessarily pretty much the same.

Open your software's coordinate system editor.

In Pathfinder Office (PO), menu to Utilities / Other / Coordinate System Manager.

Define Ocotepaque 1935 datum transformation (Molodensky)

You must define your datum first before you define coordinate systems based on it. Let's start with the Molodensky transformation of G. Stentz (NIMA).

- Go to the datum transformation section (PO: click on Datum Transformations tab).
- Open a window for defining a new Molodensky transformation. In PO the main window is split between named transformations (left) and the actual parameter setups (right). Right-click on white space in the left window to bring up a popup menu. Menu to Add New Datum Transformation / Molodensky.
- Name the transformation "Ocotepaque (Stentz)." (PO: type in the Name field. The Export Name field will automatically fill.)
- Define the datum's ellipsoid. (PO: select Clarke 1866 from the menu.) In an ellipsoid the equatorial radius (semi-major axis) a is longer than the polar axis (semi-minor axis) b . Their ratio determines the amount of flattening f , defined as $1 - (b/a)$. Most software wants you to define an ellipsoid with the values a and $1/f$. For the Clarke 1866, $a = 6378206.4$, and $1/f = 294.9786982$. For the WGS84, $a = 6378137.0$, and $1/f = 298.257223563$.
- Choose the transformation direction of your parameters (PO: click the To WGS-84 button), and enter the parameters (PO: in Translation X (m) enter 205; in Translation Y (m) enter 96; in Translation Z (m) enter -98).
- End and save. (PO: Click OK. Menu to File / Save.)

Define Ocotepaque 1935 datum transformation (7-parameter)

If you wish to define the Registro Nacional transformation (*modelo no baricéntrico*), even though it appears to produce less accurate results than Stentz's (above), the procedure is as follows:

- Open a window for defining a new 7-parameter transformation. (PO: right-click on white space in the left window. Menu to Add New Datum Transformation / Seven Parameter.)
- Name the transformation “Ocotepaque (R.N.)” and define the datum’s ellipsoid as above.
- Choose the transformation direction of your parameters (PO: click the From WGS-84 button), and enter the parameters (PO: in Translation X (m) enter 6.41; in Translation Y (m) enter -49.05; in Translation Z (m) enter -11.28; in Rotation X (secs) enter 1.5767; in Rotation Y (secs) enter 0.5242; in Rotation Z (secs) enter 6.9718; in Scale Factor (ppm) enter -5.7649).
- End and save. (PO: Click OK. Menu to File / Save.)

Define coordinate system: Cuadrícula Lambert, Costa Rica Norte.

- Go to the coordinate systems section (PO: click on Coordinate Systems tab).
- Define a set of coordinate systems. In PO the main window is split between sets (left) and system definitions (right). Right-click on white space in the left window to bring up a popup menu. Menu to Add New Coordinate System Group. Name the set “Costa Rica.”
- Define the coordinate system. (PO: In the *left* window select the Costa Rica set you just defined. Right-click in the *right* window to bring up a popup menu. Menu to Add New Coordinate System / Lambert Conformal Conic 2 Parallel.)
- Name the coordinate system “Lambert Norte” and link it to one of the Ocotepaque 1935 datums you just defined (PO: select Ocotepaque (Stentz) or Ocotepaque (R.N.) from the menu).
- Your software may allow you to default to reporting estimated elevation above sea level, using a particular geoid model. That’s fine if you only want to use your newly-defined system on your computer, but may cause memory-constraint problems if you wish to upload it to your GPS, because the system definition will attempt to drag the entire geoid file with it. I suggest you either link to a small subset file (see below) or else choose not to link, since you can always custom-link when the time comes, and geoid models are improving rapidly (PO: click Next; from the Method menu, choose No Geoid Model; click Next again).
- Define the parameters. In PO, first make sure the Positive Coordinate Direction is set so that the northing increases to the north, the easting increases to the east. Then, in Central latitude enter “10 28 00 N” to signify 10° 28' 00" N (the software will interpret the spaces to signify hexagesimal, or degree-minute-second, notation). In Central longitude enter 84 20 00 W; in False northing (m) enter 271820.522; in

False easting enter 500000; in Parallel 1 enter 11 00 00 N; and in Parallel 2 enter 9 56 00 N.

- End and save. (PO: Click OK. Menu to File / Save.)

Define coordinate system: Cuadrícula Lambert, Costa Rica Sur.

- Select the Costa Rica coordinate set as above, and proceed as for Costa Rica Norte, naming this one “Lambert Sur,” through setting the Positive Coordinate Direction. Then (PO), in Central latitude enter 9 00 00 N; in Central longitude enter 83 40 00 W; in False northing (m) enter 327987.436; in False easting enter 500000; in Parallel 1 enter 9 32 00 N; and in Parallel 2 enter 8 28 00 N.
- End and save. (PO: Click OK. Menu to File / Save.)

Define coordinate System: CRTM

CRTM is the new (1990) Costa Rica Transverse Mercator cadastral grid, which is based on the WGS84 datum. It’s likely to be the grid printed on future topo maps.

- Define the coordinate system. (PO: In the left window select the Costa Rica set. Right-click in the right window to bring up a popup menu. Menu to Add New Coordinate System / Transverse Mercator.)
- Name the coordinate system “CRTM 1990” and link it to the WGS84 datum (PO: select WGS 1984 from the menu).
- Proceed as for Lambert (Costa Rica Norte) above, through setting the Positive Coordinate Direction. Then (PO), in Central latitude enter 0 00 00 N; in Central longitude enter 84 00 00 W; in False northing (m) enter 0; in False easting (m) enter 500000; and in Scale factor enter 0.9996.
- End and save. (PO: Click OK. Menu to File / Save.)

Define coordinate systems: NAD27 UTM, zones 16 and 17

You may also wish to define the UTM grids printed on older military versions of Costa Rica topo maps, if you use any of those (these also happen to be standard transformations that you can probably define on the fly in your software). There are two, one for UTM Zone 16 and one for UTM Zone 17. Proceed as for CRTM above, except:

- Name the coordinate systems “UTM 16 NAD27” and “UTM 17 NAD27.” Link them to the North American Datum of 1927, Central America version (PO: select NAD 1927 (Central America) from the menu). If needed, the ellipsoid is the Clarke 1866 (see above), and the Molodensky transformation parameters (to WGS-84) are 0 (X), 125 (Y), and 194 (Z).
- For Zone 16, use central latitude 0 00 00 N, central longitude 87 00 00 W, false northing of 0, false easting of 500000, and scale factor of 0.9996.
- Zone 17 is identical except the central longitude is 81 00 00 W.

- End and save. (PO: Click OK. Menu to File / Save.)

Put them to use on your desktop

You are now set to display your GPS files on-screen, and export them to GIS programs, in Ocotepaque latitude-longitude coordinates, Costa Rican Lambert coordinates, CRTM 1990 coordinates, or the old UTM grid coordinates. You can also display or export estimated elevations above sea level.

- In some software (Trimble Pathfinder Office is one) you must quit and reboot the GPS-support program before the new systems will be available.
- Set up to display Ocotepaque 1935 latitude-longitude. (PO: Menu to Options / Coordinate System. Choose Latitude/Longitude from the System menu [top item on menu], then select one of your Ocotepaque transformations from the Datum menu.) Heads up: in PO, *all* files will display in this system until you change again. Note that this affects display and export only, not the GPS data files themselves.
- To display and export elevations as estimates relative to mean sea level, select a geoid model for the software to interpolate from. (PO: In the same Coordinate System window you opened, click on Mean Sea Level (MSL) in the lower half of the window. In the Geoid menu select the model of your choice—on my system, the best available for Costa Rica are EGM96, which covers the whole globe, and CARIB97 (Caribbean), which has better precision but covers nothing south of 9° N latitude.)
- Save your choices. (PO: Click OK and wait while any open files redisplay.)
- Set up to display Cuadrícula Lambert, Costa Rica Norte. (PO: Menu to Options / Coordinate System. Choose Costa Rica from the System menu, then Lambert Norte [or another of your new coordinate systems] from the Zone menu. Check that your elevations will be reported the way that you prefer, and click OK.)

Put them to use on your GPS

Some (not all) GPS units are capable of uploading datum transformation and coordinate system parameters that have been entered into your desktop GPS software. In this section I include sample instructions for a Trimble GeoExplorer III GPS (GE3). Again, the procedures for other units will be very similar.

- Connect the GPS to your computer.
- Start up the data transfer utility (PO: Menu to Utilities / Data Transfer.)
- Set it to upload files to the GPS (PO: Click Send tab).
- Select datum transformation and/or coordinate system definition files as the class of file to upload (PO: Select Coordinate System from the Add menu.)
- Upload the Ocotepaque transform file, then any coordinate systems you want to use (PO: The selection process is identical to the process for choosing an on-screen display option, above. Click OK after each, then repeat until all that you want to upload are listed under Files to Send. Click Transfer All).

- Upload any *small* geoid-model files that pertain to your field location. Note that the EGM96 file is about 4 megabytes in size, and the CARIB97 file is nearly 2 mb, whereas *total* memory on an unimproved GE3, for example, is only 1 mb. See below for creating or obtaining smaller subset files.
- When the transfers are complete, quit and disconnect.
- Select a coordinate system on the GPS. (GE3: Click the SYS button until you reach the Setup screen. Scroll to Configurations and click Enter. Arrow to Coordinates and click Enter. Generally, arrow up and down to the parameter you wish to change, then click Enter; arrow to your selection, then click Enter to choose it.
- Specifically (GE3), your Costa Rica group is under System, then Lambert Norte etc. will be under Zone, and the Datum will switch automatically for these. Or you can choose Latitude/Longitude under System, and select Ocotepeque (Stentz) under Datum.
- Specifically (GE3), you can switch between elevations relative to the ellipsoid (HAE) and relative to mean sea level (MSL) under Altitude reference, and you can choose the geoid file for MSL under Geoid.
- When you're all set, go back to normal GPS operation (GE3: Click the CLOSE button).

The GPS will now display positions in the coordinates you've chosen (but it will *record* positions in its native WGS84 coordinates—you can still display them and export them any way you wish, on your computer). Enjoy!

High-tech addendum 1: Trimble's tool for making small subset geoid files

It's very nice to be able to orienteer in the field using fairly accurate elevation estimates, from an advanced, high-resolution geoid model. Unfortunately, the better the geoid model the bigger it is, so the chances are that the model you'd prefer to use (as of this writing, probably either the EGM96 or CARIB97 model) are too big to fit on most of today's GPS units. The frustrating thing, of course, is that you don't *need* most of the information in the models. The EGM96 covers the entire planet at 15' x 15' resolution, with both poles thrown in. The CARIB97 covers the Antilles, Bahamas, and much of the rest of the Caribbean at 2' x 2' resolution. Chances are you won't cry if you have to go into the field in Costa Rica without being able to calculate accurate heights on the Ross Ice Shelf or in western Cuba. You need a cookie cutter, to make small subsets that cover just the area where you'll be working.

As it happens, Trimble includes a software tool to do just that on their Pathfinder Office CDs. They just don't tell you about it. It's called Grid Factory, and while it's kind of a programmer's tool (not terribly friendly, and comes without useful instructions), it's pretty easy to use if you do everything right. Just quit and start over if it gets confused. Here are instructions. (Note: I also currently have two general-purpose files available for download on the web. Go to <http://web.utk.edu/~utkgeog/faculty/orvis.htm> and follow the links. Both are EGM96 subsets. CREGM96.ggf covers all of mainland Costa Rica, and IslaCoco.ggf covers Isla del Coco.)

Installing Grid Factory

- Log in to your computer with Administrator privileges. Load the Pathfinder Office CD (mine is version 2.80).
- Do not double-click the CD icon. That only launches the installer for Pathfinder Office, and it never heard of Grid Factory. Open the “My Computer” window, highlight the CD icon (mine is named PFO280), and menu to File / Open.
- That brings up the E:\ window. Open the Tools folder, and within that the Grid Factory folder.
- Double-click on Setup.exe and proceed normally.

Using Grid Factory

- The installer inserts a link so you can launch from Start / Programs / Grid Factory.
- The first time, it will need to find the geoid files. They will be somewhere like C:\Program Files \ Common Files \ Trimble \ GeoData. If you save subsets in the same place, they'll be easy to find for uploading to your GPS.
- Open the file of choice. For some reason the EGM96 file is called WW15MGH.GGF. The CARIB97 file is called Carib97.ggf.
- If the map view is not useful (Grid Factory tends to remember things it was doing recently, and think it's still doing them), do the following. 1) Click the Close Grids icon on the toolbar (leftmost, looks like blank paper). That clears all active grids. 2) Select some global geoid model, like DMA10.GGF. 3) Zoom to extents by clicking the Zoom Extent icon (looks like some kind of Celtic cross). You should now see the whole globe in an orthographic projection. Keep trying if you don't. 4) Select the Pan Mode icon (pointing finger). Now when you click on the globe, it will redraw with that spot front and center. Click until Cost Rica is on your side of the planet, and then center Costa Rica on the globe. 5) Repeat step 1 (Close Grids), then open the file of choice.
- Pan (finger icon) and zoom (magnifying glass icon—also pans to where you click) until you're looking at your region of interest at a large enough scale so that you can accurately select what you need.
- Now select the Sub Grid Selection Mode icon (northwest-pointing arrow). Select the area you want by clicking and dragging from the NW corner to the SE corner. The area will be outlined in dotted red.
- The Save Sub Grid icon is now active (red square inside blue square, third from left). Click it to save you're your subset as a file (the software will add a .ggf extension).
- Clear the screen (Close Grids) and then open your new subset file. Check that it looks right, and right-click on the area within the blue rectangle to bring up a Grid Properties window. Check your extents, et cetera.
- When you've got what you want, exit Grid Factory. Remove any mistakes from the GeoData directory so you won't confuse yourself (or others) later.

You can use your subset just like any other geoid model, including uploading it to your GPS. The higher the resolution of the model, obviously, the smaller (in spatial extent) the subsets you'll want to create and use (although I expect that GPS memory constraints will disappear fairly quickly).

High-tech addendum 2: Combining mis-matched coordinates using GPS software

To translate or combine large geographic datasets with mis-matched coordinates (for example, one dataset in NAD27 UTM, another in Cuadrícula Lambert Costa Rica Norte, another in WGS84 [GPS] latitude-longitude, another in Ocotepique-1935 latitude-longitude) it's best to use a GIS utility designed for the purpose, such as the ArcView CR_PROYECCION_DATUN extension developed by the Departamento de Geografía at the Universidad Nacional de Costa Rica. However, it is perfectly possible (and sometimes handy) to translate points between coordinate systems using GPS support software.

You can also add points, collected in various systems, to a GPS file, and then export them to GIS all in a single coordinate system. For just a few points this is easier than fooling with multiple coverages in GIS. Here's how to do it in Trimble Pathfinder Office (version 2.80). Again, other software probably works similarly.

Let's say a published article mentions an important feature at 568420E, 315443N in Costa Rica Lambert (Sur) grid coordinates, elevation 634 m. You want to map that feature along with GPS data you've been collecting in the same area.

- Start Pathfinder Office and open your GPS file. (Preferably, the file should be from the same region where you want to add points, and should have a data dictionary that includes some kind of point feature with a useful comment field. If you're just translating and copying down values, that's not as important.)
- Set Pathfinder Office so it's displaying the file in the coordinate system (including elevation) of the point(s) you wish to add. Menu to Options / Coordinate System. Assuming you've set up Costa Rican coordinate systems according to the instructions in this document, select Costa Rica from the System menu, then select Lambert Sur from the Zone menu.
- You're in the south of the country where the CARIB97 geoid model doesn't extend, so you'll need to use the EGM96 geoid model. In the lower part of the Coordinate System window, click on Mean Sea Level (MSL), click on Other for the geoid model, and select EGM96 (global) from the Geoid menu.
- Click OK.
- Add your point. Menu to Data / Create Feature. You'll get a popup window that lists the items in the data dictionary you used when creating the GPS file that's open. Select a useful point feature, then click OK.

- The Create Feature window disappears and an Enter Attributes window opens. In it, the Attributes tab will be selected, so you can enter attributes. Add what you need to, for example some text to identify the point in a Comment field.
- Click on the Manual Positions tab.
- By default, the Add from Map box will be selected. Un-select it.
- The units will be Northing or Latitude first, and Easting or Longitude second, depending on the coordinate system in use. *Be careful!* In this window Northing always comes first, followed by Easting, whereas UTM and Lambert coordinates are typically listed Easting first, Northing second. Don't mix them up! (Enter latitude and longitude that's in hexagesimal, or degree-minute-second, notation using spaces, e.g. 09 57 00 N and 84 05 00 W for San Jose. Include the N and W or you'll be in Sri Lanka instead of Costa Rica!)
- In our example, double-click in the North field and enter 315443, then tab to the East field and enter 568420. Finally, tab to the Altitude (MSL) field and enter 634.
- Click Add, then click End.
- Repeat until you're done adding points that are in *this* coordinate system, then click Close in the Create Feature window.
- To proof your work, you need the Feature properties and Position Properties windows open. Menu to Data / Feature Properties, and Data / Position Properties. If you don't see your new points, zoom out (View / Zoom / Extents). Click on Last in the Feature Properties window. Proof the position you entered in the Position Properties window. If you entered more than one point, move through them with the \leq and \geq buttons in the Feature Properties window.
- To add other points that are in yet another coordinate system, change to that coordinate system (menu to Options / Coordinate System and select the appropriate choices including elevation) and repeat the above steps.
- What's the position of our example point in CRTM coordinates? Menu to Options / Coordinate System and select CRTM 1990 from the Zone menu. Reselect Other and your geoid model (CARIB97, or in the south EGM96) in the bottom part of the window. Click OK. In CRTM coordinates, your location rounds to 9822231 N, 605264 E. Elevation stays the same.
- Perhaps you want to navigate to our example position, but your GPS is not capable of uploading transformations. What's the position of our example point in "pure GPS" coordinates, i.e. WGS84 latitude-longitude and HAE relative to the WGS-1984 ellipsoid? Menu to Options / Coordinate System and select Latitude/Longitude (top of list) from the System menu, then select WGS 1984 from the Datum menu. In the bottom of the window, click Height Above Ellipsoid (HAE). Click OK. Rounded to tenths of a second, our position is 8° 53' 04.6" N, 83° 02' 33.5" W, and the HAE is 649 meters.
- If you're just translating a few coordinates, close the GPS file without saving it. Otherwise save and close the file.

There are a few points about how this all works that are important to understand. First, when you select a coordinate system in Pathfinder Office, you're only changing the way the program displays, exports, and accepts data. GPS files, including any points or other features you add by hand, are stored *only* in WGS84 and HAE coordinates. Next time you open the file it will display in whatever coordinate system is active at the time.

Second, when you change the coordinate system in Pathfinder Office, it does not change again until someone purposely changes it. If you select Ocotepaque-1935 coordinates, and two weeks later your colleague starts Pathfinder Office and examines his GPS files from Japan, he may be surprised by the strange locations he sees!

Third, when you export features from the GPS file to GIS or ASCII, *all* features, whether from GPS or entered by you in some different coordinate system, will be exported in whatever coordinate system you have active at the time of export. Unlike GPS files, the coordinates of that system are the only coordinates associated with features, and they are permanent.

Low-tech addendum 1: How to plot a latitude-longitude position on a topo map

To many people this is old hat, but I include these instructions for the uninitiated. Note that if you can do transformations as outlined above, it's a whole lot easier to plot positions that are in the local Lambert coordinates (Norte or Sur). See below.

- You have your latitude-longitude position, in Ocotepaque 1935 Datum coordinates, either calculated from GPS data as above, or from something in the literature.
Example: We took a GPS position outside the dining hall at Las Cruces Biological Station, which translates in Ocotepaque latitude-longitude to 8° 47' 13.981" N, 82° 57' 41.580" W. We want to mark its location on the topo map.
- Obtain an accurate ruler with the smallest gradations you can find. I use an engineering ruler with 1/60-inch (0.42mm) markings. I try to interpolate to a tenth of that, but I assume my measurements are only accurate to about 0.25/60 of an inch (0.11mm).
- On Costa Rican 1:50,000 scale topo maps, latitude and longitude are marked every five minutes. Latitude markings are given in each corner, and at the center of each side margin. Longitude markings are given in each corner, and twice on the top and bottom margins. In addition, there are two large "+" marks where lines connecting the edge marks would intersect. *All the other grids and marks refer to other coordinate systems, not latitude-longitude.*
Example: I'm looking at the Cañas Gordas sheet, which contains our point of interest. It extends from 8° 40' 00" N (bottom) to 8° 50' 00" N (top), and from 82° 45' 00" W (right side) to 83° 00' 00" W (left side). On the top and bottom margins there are longitude ticks at 50' and 55', and on the right and left margins there are latitude marks at 45'. The two large "+" marks on the map denote the points 8° 45' 00" N / 82° 50' 00" W, and 8° 45' 00" N / 82° 55' 00" W.
- The corners, the edge ticks, and the two "+" marks in the middle combine to divide the map into six quadrants (two rows of three across). Figure out which quadrant your location is in. Then figure out how many minutes and seconds from the *edge of*

the quadrant your location is.

Example: Our latitude and longitude of $8^{\circ} 47' 14.447''$ N, $82^{\circ} 57' 40.834''$ W put us in the upper left quadrant, which spans latitudes from $8^{\circ} 45'$ to $8^{\circ} 50'$, and longitudes from $82^{\circ} 55'$ to $83^{\circ} 00'$. Our location is $(47 - 45 = 2) 2' 14.447''$ from the bottom of the quadrant, and $(57 - 55 = 2) 2' 40.834''$ from the right edge of the quadrant.

- Change those distances into decimal minutes.
Example: $2 + 14.447/60 = 2.241'$ (latitude), and $2 + 40.834/60 = 2.681'$ (longitude). In reality you can't possibly use all those decimals— $0.001'$ is less than 0.04 mm on the map.
- As accurately as you can (interpolate!) measure the 5 minutes of latitude between marks defining the left or right margin of the quadrant, whichever is closest to your location. *Maps are really printed to scale (and paper shrinks and swells quite a bit), so never use measures from a different map, or even from the margin of a different quadrant.* I use a magnifying glass, but when I was younger I didn't have to. Write the answer down or put it in a memory register of your calculator.
Example: I happen to get 435.5 sixtieths of an inch (184.36 mm) at this moment between the top left corner of the map and the 45' tick midway up the left margin of the map. If the weather changes and I measure it again tomorrow, it will be different. If I breathe near it or lean on it for half an hour, it will also be different, so re-measure occasionally during long jobs.
- The same way, measure 5 minutes of longitude between marks on the top or bottom margin of the quadrant, whichever is closest. Write it down or put in memory.
Example: I happen to get 433.8 sixtieths of an inch (183.64 mm) between the left map margin adjacent to the 45' tick, and the "+" at the lower right corner of the quadrant.
- Divide your answers from step 5 (decimal minutes in from the edge) by 5 (the span of the quadrant in minutes) to calculate how far across the quadrant your location is, in each direction.
Example: $2.241 \div 5 = 0.4482$ (latitude or vertical), and $2.681 \div 5 = 0.5362$ (longitude or horizontal).
- Now multiply your answers from step 8 by the quadrant dimensions from steps 6 and 7, to calculate how far from the edges your location is, in the units of your ruler.
Example: The latitude or vertical offset will be $0.4482 \times 435.5 = 195.2$ sixtieths of an inch (82.63 mm), and the longitude or horizontal offset will be $0.5362 \times 433.8 = 232.6$ sixtieths of an inch (98.47 mm).
- Find your location by measuring up from the bottom of the quadrant the distance of your latitude offset, and in from the right side of the quadrant the distance of your longitude offset. Align a sheet of paper with the tick and the "+" to give yourself a border in each case. It's often easiest to measure twice in one direction, to two points on either side of the approximate location, and make faint pencil marks, so that you can line up the ruler with those marks when you measure in the other direction.
Example: See point A in Figure 6.
- If you don't want to fool with aligning a sheet of paper you can usually measure in from the opposite edge if that happens to be a map margin.
Example: Latitude or vertical would be $(1 - 0.4482) \times 435.5 = 240.3$ sixtieths of an

inch (101.73 mm) from the top map margin. Longitude or horizontal would be $(1 - 0.5362) \times 433.8 = 201.2$ sixtieths of an inch (85.17 mm) from the left map margin.

- That's the nominal location, but there's a margin of error. Around that location, how big is the circle or box that outlines the area within which you can be quite certain the GPS position lies? This GPS position happens to have a horizontal precision of 5.8 m. Add to that the uncertainty of the transformation, the uncertainties of measurement, and the fact that topo maps, like any maps, are simplified in a manner appropriate to their scale and use. Based on our experience (above), a conservative error circle should be about 2 mm in diameter, an optimistic circle about 0.5 mm in diameter, centered in either case on the point you've located.

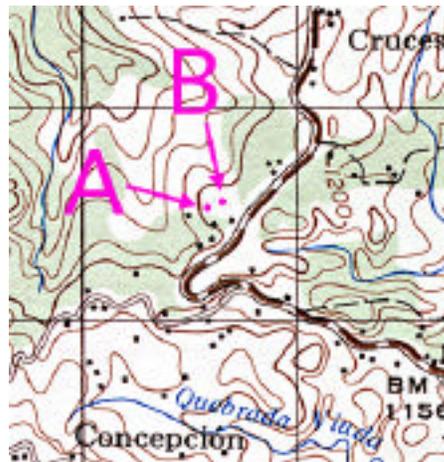


Figure 6.

Low-tech addendum 2: How to figure latitude-longitude from a topo map

Basically, do the inverse of the above. Measure the distance in ruler units from your point to the edge of the quadrant. Measure the sides of the quadrant, and divide the point-to-edge distance by the length of the corresponding side. Multiply by 5 to get decimal minutes of latitude and longitude, and then if you like remove the decimal portion and multiply that by 60 in each case to get the arc-seconds parts of the latitude and longitude. Add to your answers the latitude and longitude, respectively, of the southeast corner of the quadrant (not of the whole map sheet). There you are.

- *Example:* On the hill above Laguna Zoncho (same quadrant of the Cañas Gordas topo sheet) there's a triangulation point marked (it has an elevation of 1231 m printed in both black and brown). According to my measurements, it's 324.0 sixtieths from the bottom of the quadrant (i.e., north of $8^{\circ} 45'$) and 230.2 sixtieths from the right margin of the quadrant (i.e., west of $82^{\circ} 55'$). The quadrant is 435.5 sixtieths from bottom to top, so the proportion of that distance is $324.0 \div 435.5 = 0.7440$. The quadrant height represents five minutes of latitude, so $0.7440 \times 5' = 3.7200'$, or $3' 43.20''$ (because $0.7200' \times 60 = 43.20''$). Add that to the latitude at the bottom of the quadrant, $8^{\circ} 45'$, gives a latitude of $8^{\circ} 48' 43.20''$ for the triangulation point. As to longitude, the quadrant is 433.8 sixtieths wide, so $230.2 \div 433.8 = 0.5307$, and $0.5307 \times 5' = 2.6535'$ or $2' 39.21''$, which we add to the longitude at the right margin, $82^{\circ} 55'$,

to get 82° 57' 39.21" for the longitude of the triangulation point. These are all, of course, Ocotepeque 1935 coordinates.

Low-tech addendum 3: How to plot or figure Lambert-grid positions on a topo map

This is a much-simplified version of the latitude-longitude procedures, above. For an example, let's use an uncorrected GPS position I collected at the meteorological station at Las Cruces Biological Station. Translated to Cuadrícula Lambert, Costa Rica Sur, I have 577647 meters East, 304557 meters North.

- Obtain an accurate ruler with the smallest gradations you can find. I use an engineering ruler with 1/60-inch (0.42mm) markings. I try to interpolate to a tenth of that, but I assume my measurements are only accurate to about 0.25/60 of an inch (0.11mm).
- On non-military Costa Rican 1:50,000 scale topo maps, the Cuadrícula Lambert printed right on the map as a 1-kilometer grid. To see if you're in the Norte or Sur section, look down at the bottom center margin where it discusses "Las líneas negras numeradas." At the edges of the map, each grid line is numbered with the kilometer number: the Easting along the top and bottom margins, the Northing along the left and right margins. The hundreds place (and thousands, if there is one) numbers are traditionally printed as superscripts. Strip the last three digits (do *not* round!) off your Easting and Northing, and find your grid lines.
Example: I'm looking at the Cañas Gordas sheet, which contains our point of interest. Our Easting is 577647 meters, or 577.647 km, so we look for ⁵⁷⁷ on the bottom margin, near the left. Our Northing is 304557 meters, or 304.557 km, so we look for ³⁰⁴ on the left margin, above center.
- Follow the two grid lines and locate their intersection. That is the lower left corner of the grid square that contains your location.
Example: Where the ⁵⁷⁷ line and the ³⁰⁴ line cross is the lower left corner of the grid square north of the square containing the word Concepción.
- For many purposes you can just eyeball it at this point. The square is 1000 m on a side. The last three digits that you stripped are your address inside the square, with 0,0 at the bottom left.
Example: We're 647 meters east of the left edge of the square, and 557 meters north of the south edge. That would be somewhere near the big leftward bulge of the heavy contour.
- Since this is a Lambert grid on a Lambert-projection map, the grid cells should be true squares. Whether you want to believe that I'll leave to you. In either case, multiply your measurement of the square by the proportion of a kilometer represented by the last three digits that you stripped. Then measure that distance in from the edge to find your location.
Example: At the moment I get 47.7/60 of an inch east-west, and 47.6/60 of an inch north-south. $0.647 \times 47.7 = 30.9$ for the Easting, and $0.557 \times 47.6 = 27.5$ for the Northing. My measurement puts us at point B in Figure 6.
- That's the nominal location, but the same margin of error applies as above (there is no error due to changing from Ocotepeque latitude-longitude to Lambert, because that's

an exact transformation). Again, based on our experience, a conservative error circle should be about 2 mm in diameter, an optimistic circle about 0.5 mm in diameter, centered in either case on the point you've located.

To work backward, do the inverse. Measure the distance from your point to the south (Northing) and west (Easting) edges of the grid square it's in. Calculate the proportions of the grid-square dimensions that those numbers represent (e.g., the middle of a square would be .500 E, .500 N). Follow the grid lines from the lower left corner of the grid cell to the edges of the map, and copy down the numbers you find there, including the little raised digits. The number from the top or bottom edge is your Easting, and the number from the right or left edge is your Northing. Add your Eastings and your Northings together (e.g., $586 \text{ E} + .500 \text{ E} = 586.500 \text{ E}$; $296 \text{ N} + .500 \text{ N} = 296.500 \text{ N}$). Now multiply both numbers by 1000 to get the Lambert address in meters (585500 meters East, 296500 meters North).

Reference:

Mugnier, C. J. 1999. The Republic of Honduras. Monthly "Grids and Datums" column. *Photogrammetric Engineering and Remote Sensing* 65(7): 754–755.