DR. ROMAN: Dave's instructions to me were to make your ears bleed; very well, I will. (laughter) Grab the armrest, and hold on tight. I got 33 slides in 33 minutes.

Next slide please.

All right, these are the areas we want to try to focus on. The bottom line is that basically, we've got a perspective from where we are and where we're going and I want to talk a little bit about where we are and a little bit where we are going. (Referring to slide) So, that's our role.

Next slide please.

Datums per se, basically, when you talk about datums, everybody seems to think about the surface. When we talk about actually trying to realize that, it becomes a bit more of a problem.

Next slide.

In defining a particular geopotential surface or some such thing that describes a surface from which we will measure heights: where is "zero"? You know, is it the stage, or is it the floor? It all matters, because if you're measuring to this object are you starting from the floor from the stage? So you need to establish where the zero level is. So once you have that assigned, then the question becomes how do you access it and what are you going to use to make those measurements?

Next slide.

Alright, then as an example is the North American vertical datum. If you look at it and it says 6-point-plus meters there below the point of Father Rimouski there you have a geopotential surface and that is the surface from which we are going to measure things. Great. But in fact, it is hard to measure a geopotential surface anywhere. So what you would typically end up doing in terms of the realization, you measure from mark to mark and you look at the difference in heights. So then, you describe your heights with respect to this mark but the way you realize it is through the bench marks. So that is how you access it, not the geopotential surface itself.

Next slide.

By way of limitation then, the datum itself that is defined is not in fact a surface; it's a cloud of points. We note in here, it is fairly obscure in this chart but these are the level of primary, secondary and tertiary (points) that were used to define NAVD 88 across the country. So these first off, are not a surface. It's a series of loops. And, in fact, those loops are not completely filled in but they're a series of connected dots where you have the height difference between them and those were all adjusted together. So the biggest thing to understand here is that NAVD 88 is itself not a surface but a cloud of points realized together as an adjustment. All tied to Father Point/Rimouski and all ostensibly removed from ties to sea level, which was the problem with NGVD 29.

But, nonetheless, this is immediately a limitation here. For starters you've got 450,000 bench marks within CONUS, about 500,000 total. There were some into Canada and Alaska and down into Mexico to some extent as well. The bottom line is, those marks are static, they're not accounting for and of the time variations that might cause the ground to subside or even in some cases uplift. And then those marks of course are subject to a few other problems.

Next slide.

One of the biggest problems is that those 480,000 points or 450,000 points that are in the U.S. probably not most….I would not say all of them are there any more. They have a bad tendency to disappear, they get bulldozed or the worst case is when a contractor will come in, remove it, do whatever work he's going to do, and put it back because it says to leave it there. [Laughter]. Okay, great. So, reliability of the marks becomes very much called into question here. As you go through, you can see some of the other problems but you can see the Canadians even though they worked with us on this, did not like some of the problems that they saw, that arose after the adjustment so they never ended up adopting it, even though we use it in Alaska, marks continued on through Canada into Alaska.

Some of those reasons for that are quite obvious here, and in some of the later slides I'll show you. But basically, as you do the adjustment, any errors that you have will build up in the adjustment particularly as you propagate them across the country. So taking something across 5,000 kilometers you are going to accumulate a few errors and in fact, we do.

Next slide, please.

What are we looking for? The first one, I can forgive and deal with, the fact that there is a bias. Ok, I can pick a different geopotential surface. That's fine, or at least apply a bias corrector. The second one is much more problematic because NAVD 88, to have a tilt means that with respect to the GRACE gravity field data means it is, in fact, not a geopotential surface. In fact, that is what it was intended to do – it is supposed to realize a common geopotential surface across the country and in fact, it does not. So that is one of the immediate problems you have with it is the accuracy.

We already know it is not a geopotential surface and does not provide an accurate means of determining heights across the country. So I can maybe faithfully replicate it but in terms of it being accurate, that I can't claim.

Next slide, please.

Continue, this is a bit more and we have to build here. And one more. Okay, one more. And one more.

The difference here is that basically, I'm trying to show a geopotential surface, the ideal one, the geoid, the best one fitting mean sea level in this case and NAVD 88 as a surface. This is showing a cross section, basically that there's an offset and it is not just a simple bias, that there

is some value that can apply to offset from one geopotential surface to another. In fact, it varies across the country.

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This is showing it in plan view. If you note the color scale on the right, you will see there is indeed about a major tilt across the country. This is basically derived in comparison of our GPS leveling, GPS that were after the national readjustment that are fairly consistent at the centimeter level and also, compared to the GRACE geoid which is also consistent at the centimeter level, at long enough scales so when we compare it to the levels we apply a filter and try to remove the higher frequency/shorter wavelength differences that you might see. But what you still see are the long wavelength differences between NAVD 88 and the geopotential surface that GRACE kind of determines for the country. What this is pointing to, is what I mentioned before is the cross country tilt that we are talking about.

Where this becomes a problem, is when you are talking about accuracy where you want to try and tie it to the ocean surface. Okay, you can get consistency across the country, and that is one of the things that I do right now with the modeling approach is try to faithfully replicate this systematic effect. But, keep in mind that what you are seeing here is the misfit, if you will, between the geopotential surface that may be the best one to tie into mean sea level, and our datum that we have for a vertical reference onshore. So there is a misfit between what we are tying on land and with what might be happening with respect to the ocean surface.

Part of the work we'll be looking to in the future is trying to make this a better tie, trying to understand this relationship so we can express it so when we talk about oceanographic phenomena how they transition of the shoreline, we can have our terrestrial reference frame in the same framework. And, of course, it's not a perfect fit and there's plenty of work to be done there.

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Short term fixes: We are doing Height Mod surveys, things that are basically designed to try and help us along. The longer term fixes are basically looking at either re-leveling or replacing NAVD 88.

Next slide.

For the short term solutions. Height modernization surveys. Basically taking a geoid model – the model of the existing data and the conversions between our ellipsoidal and vertical reference frames and trying to fit through the GPS on limited vertical marks – and we'll provide some cartoons to try to show these a little bit later what I'm trying to describe in words here – to try and use GPS to try to help fit new vertical control at various locations.

Well, that immediately calls into mind the limitations that I mentioned already that NAVD 88 may be precisely replicated but is not necessarily accurate in terms of some of the control data that I will get into here in a minute.

Next slide, please.

The control data: All those 450,000 marks I mentioned or 500,000 if you include that data that were up into Canada and Alaska, I only have about 20,000 where I have GPS on a bench mark. The reason that's important is that is the GPS derived ellipsoidal height on an orthometric bench mark. So I have both heights. The difference between them provides me separation between NAD 83 and NAVD 88. Of those 20,000, however, you will see that they are not very equitably distributed. So some states have been a little busier than others and they therefore will see a little more consistency in this conversion surface between NAD 83 and NAVD 88. So that's good because when you get to the western states where the loops are larger and you see a lot sparser data sets, the interpolation that happens between those points, this is the control data, this is how I staple the gravimetric geoid to make sure it fits between NAD 83 and NAVD 88. The farther apart those points are, the more interpolation can occur in between. Naturally when you get to Minnesota and Wisconsin and the Carolinas you don't have so much of a problem with that. But, you still are stuck with the fact that the datum itself has a systematic error in it.

Next slide please.

So then, the other approach, for the longer term is let's try to replace it. We can re-level it, $200 million to 2 billion-dollars. We are still stuck with the same problem. So…passive set of marks, errors building up across the country and you're not accounting for any of the dynamics that are occurring over time. So for all that money that you put into it, you end up with the same problems that you have right now. The other approach then…

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…would be to replace it, GRAV-D is Gravity for the Redefinition of the American Vertical Datum. Instead of trying to define a set of points that are essentially controlled through these passive marks that are not necessarily equitably distributed, instead rely on other information that maybe is more complete in terms of coverage from terrestrial models, from satellite models, from airborne observations and other surface observations, build that into one consistent model with information everywhere, even across those areas where you saw gaps before. That is what the idea is behind GRAV-D.

Next Slide.

Alright then, so the tradeoffs. Okay, you're basically going to take a GPS receiver and a geoid height model and you're going to put the two together to come up with your orthometric height. Errors in the GPS and errors in the geoid height model are going to propagate and basically that's what you are going to end up with then in terms of the error that you end up with your orthometric height. So things that can be used to try to mitigate either the geoid error and/or the errors that you arrive at with the ellipsoid height will help to improve it, but at this point, we are still looking at centimeters of error. On the other hand, I'm looking at meters of error with respect to NAVD 88 in terms of accuracy. That, actually, would represent an improvement. The other part behind this is trying to get consistency across the country. If you put a GPS receiver

down and use the model in California, Florida, Alaska, Puerto Rica and Hawaii, the idea is that you get consistency. Yes, you might have a couple of centimeters of variability, but to have consistency across all the regions provides a certain amount of ability to sit there and provide models across those regions.

Next slide.

Not really wanting you to take much away from this other than the fact that the gravity…we have Gravity for the Redefinition of the American Vertical Datum. Well, how do you get from gravity to heights? The important thing to take away from here is that the gravity along the plumb lines and the heights along those plumb lines and the geopotential surfaces are all related to the masses of the earth. So if you collect gravity, you can necessarily derive some information about the geopotential surfaces particularly the one you want to define your heights from – the geoid. So that's why collecting gravity data actually gets us heights or gets us the surface from which we're going to measure heights. That is probably the biggest take away from this slide.

Next slide.

From this one, we're in a sense, going to be building the information from a number of different sources. We're going to start with GRACE and GOCE satellite missions – they're providing consistent gravity field information over the entire plant. We can build on that because that is certainly what a lot of the other nations are going to be building on and we will immediately start from the common framework there and provide models that are consistent across the North American region, as well as, around the world. Adding in to that information is what the airborne surveys are looking at. The airborne surveys are going to kind of pick it up here. The GRACE and GOCE satellite missions are going to go about maybe 200 kilometer wavelengths or so. The airborne and surface gravity data are going to pick up from there and continue on down to the shorter wavelengths and we will basically be using that to try and define most of the gravity field. But the shortest wavelengths actually come from the variations between air and rock. If you've got a mountain and you've got air, then, you've got your biggest density contrast. So terrain models, and to a lesser extent but ones we still are going to take a look at are digital density models both horizontally and vertically, are going to be used to try to describe the shortest wavelengths of the gravity field and the idea then is to try to meld all these together so as to come up with a seamless, accurate gravity field that we can also use to express either the geopotential surface, orthometric height and/or having masses known then, the gravity field known, you can also get dynamic heights or other types of heights. So you have consistency then in terms of the way you are using the gravity field to try to determine these heights.

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All right, for the international aspects, Canada is already moving in the direction of adopting a gravimetric geoid based vertical datum. That is the same direction we are going to be going. Mexico, some Central American countries, and the Caribbean nations have expressed interest in this; they haven't necessarily stated that they are going to go completely into adopting such a thing, but they are very much interested in what we produce. I'm interested from the transparency point of view. The model, you can't just stop the gravity field information at the

border and say “Okay, that's it, I'm done”. The effect of the masses over the border, have long wavelength implications and they’re going to affect the geoid model within the U.S. Therefore, I need information across most of North America if I want to get the best model for the U.S. An added benefit to that, then, is working in collaboration with our partners in the region is we end up with a model consistent across all North America. That aids transparency in terms of trying to do heights across the border. So if the Canadians end up adopting the similar or the same gravimetric geoid, then we’re in a position to start talking about comparing heights across the border. I do get a fair number of questions, “How do I do this in Mexico?” “How do I do this in Canada?” Right now, it's very complicated. If we are actually using the same type of reference framework, using GNSS in conjunction with a common gravimetric geoid based model, then we would actually be in a position to actually describe things. Keeping in mind they are sovereign countries, they can do as they choose, and certainly I’ll be referring anybody who asks questions to my counterparts in those countries, but certainly it becomes an easier method in making these transformations when you are working across borders.

Next slide please

Primary access. The idea as I stated was basically to use a GPS receiver, or GNSS receiver I should say, and occupy a spot, get your coordinates in an ellipsoidal framework and basically then use the – interpolate the model to that location to come up with your geoid height value and apply that to come up with an orthometric height. That seems straightforward but, of course, there is a lot more that goes into that. Nonetheless, that's how you can go through this without setting a passive mark unless you choose to. If you want to set your own mark, you can do that. Or you can occupy an existing mark and you can assign the value to that or we could. But again, we are trying to distance ourselves from that approach.

Next slide please.

Now, there is a built slide here but I want to talk to it a little bit here as we go through. Basically, the idea behind it is the ellipsoidal height is equal to the geoid height approximately plus the orthometric height. And I say "approximately" because the difference actually deals with the deflection of the normals to the plumb line, or, if you will, the geoid and the normal to the ellipsoid. So if you neglect that, which can be at the millimeter level, then it is a true statement. The reason I'm showing you this right now – next slide please, or next build. There you go. This is the surface we are trying to describe, the geoid. The geoid can be expressed as a geopotential surface. Well, how do you get to that height? This is what we're trying to approximate with NAVD 88.

Next slide.

And these are the heights we are trying to build from it. So, instead of going through this approach of trying to define the geopotential surface and heights above that, instead, we want to describe the geoid height model. That is the heights from the ellipsoid to this geoid surface. And this is more solid than just a series of points that we’ve had before where we had the bench mark control, depending on the interval of the data that I want to grid down to. In particular we are looking at about one minute because we are finding at about one minute, the omission error is

typically under the centimeter level that we are looking for in terms of absolute accuracy. In theory, you'd have to get in smaller and smaller intervals to have complete coverage of the surface instead of discreet sample if you want to completely omit, or cause your omission error to go away. Well, obviously, we can't do that; we can't provide such a grid at this point. Maybe in the future – I can't think of a way to do that at this point but right now, we see that at a one minute grid, which is currently what we're using with our models is sufficient to describe the heights to a level that the omission is within the error of bars that we would be looking for. This isn't talking about the commission error, which has to do with the quality of data. Omission is how much you're neglecting. So…

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…the big take-away then, is instead of using…the idea is to use and ellipsoidal height and a geoid height model to build your orthometric height. So that's the idea behind this is to use the model, interpolate it to where you have your GNSS observation and provide you your estimate of the orthometric height. Again, this doesn't necessarily take the place of doing a local leveling survey, but it certainly is your starting point to make sure you're consistent with any other mark within the country and the framework we are trying to define here.

Next.

All right, passive marks again, we're trying get away from them, but we can certainly use this system to define a height at that particular location. Again, if you can do it on-the-fly, then why would you necessary want to occupy a passive mark, again noting the passive mark might subside or climb or change its position.

Next.

All right, conversion will be provided to NAVD 88 in the new datum.

Next slide.

One thing I want to point out here (next)…what this is is the conversion surface (not including the ellipsoidal shift) between the geopotential surface I use to define USGG2009 and the NAVD 88 surface. This is essentially what I applied to convert from the gravimetric geoid to the hybrid geoid, or from the geopotential surface that I use in USGG2009 to NAVD 88. This is "VERTCON 3.0" or whatever we want to call it. This is the difference between the geopotential surface we are looking at as a new datum and NAVD 88 determined from those control points that I described before, keeping in mind that those points are scattered particularly more so in the west, that they are not equally distributed, that the quality is not necessarily there. That's what's already in the models that we're using to do height modernization. So certainly, I already have the ability to produce a model for the transformation from one set of heights to another in a grid format, so that if you need to convert back and forth, it exists. I will also point out here that the sense of the sign is reversed by the way we subtracted, you will note there is also still a one meter slope across the country. That is the primary signal in the tilt in NAVD 88, but you also see some smaller departures as well. Keep in mind that when I did the comparison with the

GRACE and the GOCE…actually the GRACE field only, I can only compare at those scales, at those wavelengths that GRACE is sensitive to. All these differences, some could be NAVD 88. More than likely it's also in the gravimetric geoid or could be within the GPS. So I can't ascribe that to any of these so I'm not at this point, the shorter wavelength information. But as we gain more fidelity on the information from the satellite models and from other sources, we will be doing a better and better job of trying to describe where we think these errors are coming from and provide a model of these, ultimately describing what we think the errors in NAVD 88 are. But to also provide a model of that so you can make the transformation back and forth.

Next slide.

These are a series of cartoons I was trying to describe. Build this please…might be a couple of them. All right, this is the scenario…the house is built in '54, the ground has subsided since then, quite substantially (build again), and there is where you are actually located.

Next slide. Next. And again, and again.

So what this is showing then is what your actual height is at a given location compared to what you think it is which is important if you live in the flood plains. Unfortunately, if you go to that bench mark, it will make you think you're at that height, the former height, and you have no other information about subsidence. That's the problem with a static set of marks. (Next) So then, this is your true height, how are you going about this one? (Next) So, we want to try build this instead using future techniques. Right now, you would basically set your GPS receiver (go ahead and build this, go back one, just one slide. She can go back.) The idea is to occupy that mark, set it yourself, get it in contemporary coordinates in an ellipsoidal framework and tie it within the geoid value and the idea is you're monitoring the ellipsoid coordinates so you know the ellipsoidal framework is changing and you can fly over this area with LIDAR surveys particularly if you're really concerned, which is what they're looking at in some places like Louisiana and places along those lines and you can map the change in the surface in ellipsoidal coordinates, and then knowing the mass changes, you can also change the datum, if you will, the geoid changes so that you can map out the total changes in the orthometric height at this location over time. So in an instant, you can go out at any given epoch and say "what are the actual heights at this location?" And with respect to the areas surrounding it because a lot of these regions, particularly, Louisiana they don't subside at constant rates – it's not like the whole area goes down, some go down at different rates which may change your flood patterns.

Next slide.

This is showing how we would do it right now. Build this. All right. And build again. And again. One more time. That's what I was looking for. The idea, you have the mark that you're interested in. You have to go find a level line and level of people to walk from one mark tour interested area of interest and level and try to tie them in. Well, you are paying a crew of people to walk suddenly 75 kilometers, or so, and you have to close the loop and double that, 150, so you are paying for this and you still tying into the same datum.

Next case.

Build. So, how do we want to do it with the height survey? Go ahead and build. See how many of them already, build again, and again. And there we go, and keep going. What we are looking at is, basically, tying in with GPS, off some of the tasks and GPS station and use the geoid height model again to tie together those 20,000, or so, and equitably distributed points of certain quality. But the only ones we have, and use that model and this region to build, at your area of interest, the triangle.

So next slide.

And that's how you end up trying to constrain it, build it from the control network because you build it tighter and tighter. All right, next. And again. So how you do it with GRAV-D? Set up your GNNS receiver and you're done, no leveling survey, no set up, no tying in, no adjustment, you tie in one mark and you're done, a lot more straightforward.

Next.

Submit the data and some of the other additional information, talked a little bit about the ten year plan. The GRAV-D project is up on the website, you certainly can find a lot of information up there. As we collect the areas for information, we will be putting where we collected or plans for collection in the future up on the website, information about processing and things like that. I would point out that we do intend off this website, the GRAV-D website as we continue to clean up the gravity data and try to continue to build models, put those particular models on this website, and you do not want to confuse them with the existing models out there that people are using for transformation. We put them here because they’re going to be a part of GRAV-D project and ultimately, the final project. But trying to make sure class distinction between the projects kind of demonstrates you will of where we are going and the products that are out there for use right now, and of course, the social economic benefits, and I want to mention some of the colleagues work with, I'm not sure if I got I think I've mentioned one but, a number of others in the GRAV-D site as well as the modeling. I don't know if where we stand on time, but thank you.