Survey grade GPS

(or enough information to be very dangerous)

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- GPS is old school
- The correct term is now GNSS (Global Navigation Satellite System) which includes
- Old school GPS
- Glonass (Russian)
- Galileo (European Block)
- Beidou (Chinese, also called Compass)
- This talk will use GPS/GNSS to mean the same thing.

- GPS is based on an ephemeris that defines a location of a specific satellite at a given time
- GPS errors (mostly systematic)
- (1) satellite position not known perfect (ephemeris)
- (2) satellite time (atomic clock) not perfect (ephemeris)
- (3) modeling the atmosphere GPS passes through

(1) satellite position not known perfect (ephemeris)
(2) satellite time (atomic clock) not perfect (ephemeris)

Note if we could create the perfect ephemeris that is controlled by the perfect atomic clock the errors of (1) and (2) would go away!!!!

(3) modeling the atmosphere GPS passes through

Note if we could perfectly model the atmosphere real-time and correct the information real-time systematic error #3 would be eliminated

- (1) satellite position not known perfect (ephemeris)
- A satellite path is "controlled" by its speed and direction that trying to "model" gravitational effects so that it can travel a defined path
- This is as easy as trying to drive a defined path while texting with one hand and eating a What-a-burger with the other hand.

(2) satellite time (atomic clock) not perfect (ephemeris)

- It is actually hard to separate (1) from (2) as a portion of position being wrong is due to the atomic clock being wrong.
- Since satellites travel relatively quickly small error in clock results in error in position of significant magnitude

- (3) modeling the atmosphere GPS passes through
- If we could do this then all weather reporting would be perfect, except weather reporting is often long range predicting. With GPS we need no long range predictive model.
- Note precise GPS still utilizes an “elevation mask” of 10-15 degrees. In other words near the horizon the GPS data is so affected randomly by the atmosphere it is simply not useable. Note there has been no solution to this problem since the invention of GPS in the 1980’s.

- (3) modeling the atmosphere GPS passes through
- Precise GPS uses more than one unit (receiver) in a “differential” process between multiple units.
- When units are very close to one another the assumption of same weather/atmosphere is usually very valid
- As distance between receivers grows software can no longer assume the same atmosphere exists. This makes precise solutions extremely more difficult.

- What has really improved in GPS mathematically
- (1) The raw broadcast ephemeris is closer to correct than it was several years ago.

This allows for faster solutions of survey quality. Basically you are starting closer to the truth so getting to the truth is easier.

(2) The atmosphere solutions for differential GPS over long distances has dramatically improved.

This mean survey quality over lines previously judged “too long for good results” is dramatically improved.

- What has really improved in GPS mathematically
- (3) multipath mitigation
- Multipath is the bounce of GPS signal off something instead of coming directly into an antenna
- Wet pine needles are historically amazingly powerful at creating multipath problems
- Antennas and software improvements have knocked down the affect of multipath – too bad you don't really notice the improvement as you don't see what would have happened 15 years ago.

- GPS on the ground measures the incoming angle of the GPS wavelength (time based) but it does not initially know how many wavelength it took to get from satellite to the ground GPS
- Handheld and car GPS solve for point position using a minimum of four satellites using one wavelength called L1.
- The handheld/car GPS solution is called a point or autonomous position and varies in quality from 1 to 30 meters. Quality is a function of satellite geometry (PDOP), number of satellites, and quality of signal (trees, buildings, etc. block signal to varying degrees)

- Augmentation – enhancing a point position in real time
- 2 examples

- **Wide Area Augmentation System**
- From Wikipedia, the free encyclopedia
- WAAS system overview
- The **Wide Area Augmentation System** (**WAAS**) is an air navigation aid developed by the Federal Aviation Administration (prime contractor Raytheon Company) to augment the Global Positioning System (GPS), with the goal of improving its accuracy, integrity, and availability. Essentially, WAAS is intended to enable aircraft to rely on GPS for all phases of flight, including precision approaches to any airport within its coverage area.[1]
- WAAS uses a network of ground-based reference stations, in North America and Hawaii, to measure small variations in the GPS satellites' signals in the western hemisphere. Measurements from the reference stations are routed to master stations, which queue the received Deviation Correction (DC) and send the correction messages to geostationary WAAS satellites in a timely manner (every 5 seconds or better). Those satellites broadcast the correction messages back to Earth, where WAAS-enabled GPS receivers use the corrections while computing their positions to improve accuracy.
- The International Civil Aviation Organization (ICAO) calls this type of system a satellite-based augmentation system (SBAS). Europe and Asia are developing their own SBASs, the Indian GPS Aided Geo Augmented Navigation (GAGAN), the European Geostationary Navigation Overlay Service (EGNOS) and the Japanese Multi-functional Satellite Augmentation System (MSAS), respectively. Commercial systems include StarFire and OmniSTAR.

- **Accuracy**
- The WAAS specification requires it to provide a position accuracy of 7.6 metres (25 ft) or better (for both lateral and vertical measurements), at least 95% of the time.[2]
- Actual performance measurements of the system at specific locations have shown it typically provides better than 1.0 metre (3 ft 3 in) laterally and 1.5 metres (4 ft 11 in) vertically throughout most of the contiguous United States and large parts of Canada and Alaska.[3] With these results, WAAS is capable of achieving the required Category I precision approach accuracy of 16 metres (52 ft) laterally and 4.0 metres (13.1 ft) vertically

- The **Quasi-Zenith Satellite System** (QZSS), is a proposed three-satellite regional time transfer system and Satellite Based Augmentation System for the Global Positioning System, that would be receivable within Japan. The first satellite 'Michibiki' was launched on 11 September 2010.[1] Full operational status is expected by 2013.[2][3] In March 2013, Japan's Cabinet Office announced the expansion of the Quasi-Zenith Satellite System from three satellites to four. The $526 million contract with Mitsubishi Electric for the construction of three satellites is slated for launch before the end of 2017.[4]

- **QZSS and positioning augmentation[edit]**
- The primary purpose of QZSS is to increase the availability of GPS in Japan's numerous urban canyons, where only satellites at very high elevation can be seen. A secondary function is performance enhancement, increasing the accuracy and reliability of GPS derived navigation solutions.
- The Quasi-Zenith Satellites transmit signals compatible with the GPS L1C/A signal, as well as the modernized GPS L1C, L2C signal and L5 signals. This minimizes changes to existing GPS receivers.
- Compared to standalone GPS, the combined system GPS plus QZSS delivers improved positioning performance via ranging correction data provided through the transmission of submeter-class performance enhancement signals L1-SAIF and LEX from QZS. It also improves reliability by means of failure monitoring and system health data notifications. QZSS also provides other support data to users to improve GPS satellite acquisition.
- According to its original plan, QZSs was to carry two types of space-borne atomic clocks; a hydrogen maser and a rubidium (Rb) atomic clock. The development of a passive hydrogen maser for QZSs was abandoned in 2006. The positioning signal will be generated by a Rb clock and an architecture similar to the GPS timekeeping system will be employed. QZSS will also be able to use a Two-Way Satellite Time and Frequency Transfer (TWSTFT) scheme, which will be employed to gain some fundamental knowledge of satellite atomic standard behavior in space as well as for other research purposes.

- Survey grade GPS (sometimes good to .01 ft.)
- Often uses two GPS frequencies L1 and L2
- 3rd frequency L5 is on newer satellites but not yet functional
- Survey grade single frequency GPS costs approximately $6000 for 3 receivers
- Survey grade dual frequency GPS costs approximately $20000 per receiver
- But dual frequency is 10-50 times faster to use than single frequency!!! In long term dual frequency saves money.

- **Third Civil Signal: L5**
- **Status**
- Pre-operational signal broadcasting from 7 GPS satellites (as of November 7, 2014)
- Began launching in 2010 with GPS Block IIF
- Available on 24 GPS satellites around 2021
- **Features**
- 1176.45 MHz
- Highly protected Aeronautical Radio Navigation Services (ARNS) radio band
- Higher transmitted power than L1 C/A or L2C
- Greater bandwidth for improved jam resistance
- Modern signal design (CNAV), including multiple message types and forward error correction
- Bi-Phase Shift Key (BPSK) modulation
- Includes dedicated channel for codeless tracking
- View full technical specifications
- L5 is the third civilian GPS signal, designed to meet demanding requirements for safety-of-life transportation and other high-performance applications.
- Its name refers to the U.S. designation for the radio frequency used by the signal (1176 MHz).
- L5 is broadcast in a radio band reserved exclusively for aviation safety services. It features higher power, greater bandwidth, and an advanced signal design.
- Future aircraft will use L5 in combination with L1 C/A to improve accuracy (via ionospheric correction) and robustness (via signal redundancy).
- In addition to enhancing safety, L5 use will increase capacity and fuel efficiency within U.S. airspace, railroads, waterways, and highways.
- Beyond transportation, L5 will provide users worldwide with the most advanced civilian GPS signal. When used in combination with L1 C/A and L2C, L5 will provide a highly robust service. Through a technique called trilaning, the use of three GPS frequencies may enable sub-meter accuracy without augmentations, and very long range operations with augmentations.
- In 2009, the Air Force successfully broadcast an experimental L5 signal on the GPS IIR-20(M) satellite. The first GPS IIF satellite with a full L5 transmitter launched in May 2010. Like L2C, the L5 broadcast will not include a data message until the GPS control segment is upgraded.

- **Question #1:** What impact will L5 have on RTK networks?
- **Gakstatter comment:** Great question. There's only upside in having another GPS frequency to work with. Since the premise behind RTK Networks relies heavily on atmospheric modeling, L5 is going to help. It's further separated, with respect to frequency, from L1 than L2 and the signal is much stronger than L2. L5 will go a long way in mitigating the effects of the atmosphere on high-precision GPS positioning.
- They logistics of implementing L5, by the manufacturers, into RTK Networks may not be so easy. I'm not sure that L5 has been defined well enough in the RTCM specifications and even if it was, I'm not sure how fast manufacturers would implement it. Take, for example, L2C. Even though there are eight satellites broadcasting L2C, I'm not sure there are any RTK Networks taking advantage of it and transparency between different rover manufacturers. However, my gut tells me that manufacturers will be more willing to jump on the L5 bandwagon with a sense of urgency due to the potential significant increase in receiver performance.

- **Question #4:** What accuracy can be expected from single frequency L5?
- **Gakstatter comment:** It's going to be better than L1 C/A due to the stronger signal strength (4 x more powerful than L2C) and much longer code structure (than even L2C). With SBAS corrections, we're seeing about 60cm now with L1 C/A. It will probably be slightly better than that and definitely more robust positioning in marginal GPS conditions.
- He means real time 60 cm single receiver

- **Question #5:** What sort of base line distances can we expect to get with L5?
- **Gakstatter comment:** Using L5 will definitely help with longer baselines, but baselines are already pretty long. Look at the distance between reference stations in RTK Networks today. Some are pushing 70-80km. Will they go longer than 100km? I'm not sure. That would be cool, lowering infrastructure costs of setting up and operating RTK Networks.

- Researchers at the University of New Brunswick were among a few scientists worldwide to pick up a new GPS signal last week.
- University of New Brunswick geodesy and precision navigation Prof. Richard Langley operates an advanced satellite navigation receiver that helped them find a new GPS signal. The test signal was transmitted by the recently launched IIF-1 satellite, a new breed of GPS satellite that delivers a new, stronger signal, said UNB researcher Prof. Richard Langley.
- Before now, there were two frequencies, L1 and L2. The new frequency, L5, will enable navigation and positioning where signals are blocked by trees or buildings, said Langley and that himself and other researchers knew the satellite would be testing its L5 frequency, but they weren't told when it would happen. On Thursday, Langley picked up what he said was the first of many tests.
- "It will take a three-month period of testing before the signals are validated and the satellite is deemed healthy, the measurements taken during the test show the improved performance of the new signal", the satellite was over Europe and Asia when the UNB GPS system picked up the signal."We were able to catch it from Fredericton and then it was tracked from the stations to the east of us".
- There are 30 GPS satellites in orbit making up a constellation. To locate a position, a GPS device measures the distances between four or more satellites. In the years to come, new IIF satellites will replace the old satellites that are retired, so the L5 frequency can be used in commercial aviation to help landing planes. The new frequency can't be picked up by regular global positioning systems such as the one's found in cars or cellphones. L5 can only be received by researchers and surveyors with the new GPS technology, said Langley.
- Neil Gerein, aerospace and defense product manager for NovAtel, a GPS manufacturer in Calgary, said it will be a number of years before everyday people are using the L5 frequency.
- "The GPS satellites are launched one at a time, so it will be about eight to 10 years until a full set of 24 satellites is capable of transmitting L5," he said.
- Langley's lab provides information to NASA and the U.S. National Weather Service.
- He said the data he gains through the new signals will assist in the study of the atmosphere's effect on GPS systems.

- Why L5 Will Rock
  The oncoming new signal will bring significant benefits to the high-precision user. Its most important uses will come in aviation, however.

  L5 will bring to an end the era of worrying about ionospheric activity. At 1176 Mhz, the L5 frequency separation from L1 (1575 Mhz) is significant enough that high-grade, triple- or even dual-frequency L5-capable receivers will mitigate the ionospheric refraction down to a nearly negligible factor. Because ionospheric refraction error is inversely proportional to frequency squared, ionospheric error at L2 is 65 percent larger than at L1, and at L5 it's 79 percent larger.

  L5's broadcast strength will be roughly four times that of L2C. A stronger signal combined with a superior code structure means that you'll get more robust performance in tough GPS conditions. That's great news for high-precision users working in marginal GPS conditions.
- http://landsurveyorsunited.com/m/group/discussion?id=544331%3ATopic%3A7529

- Finally, in December 2005, in a Directions essay that he titled "The End of the Beginning," Per Enge wrote:

  The forthcoming diversity of signals (L1/L2/L5) will obviate the danger due to accidental radio frequency interference (RFI), do much to tame the ionosphere, and mitigate multipath. This year, GPS has launched the first of the Block IIRM satellites that includes the civil signal and code on the L2 frequency. Within a few years, GPS satellites will have three civil frequencies. The third signal, L5, will be the most effective of all, 5 or so dB more powerful than L1, with a chipping rate of 107 chips per second (or 10 Mcps) compared to the 1-Mcps codes used by L1 and L2.
- http://landsurveyorsunited.com/m/group/discussion?id=544331%3ATopic%3A7529

- "Differential" GPS – the world's most undefined term
- Method (1)
- In non-survey applications "differential" applies to any correction to a point position
- Example
- A point position on a permanent base is off from the known coordinates by 1.3 m. in latitude, 2.3 m. in longitude, and -2.9 m. in ellipsoid height.
- This offset is sent via cell or other communication mechanisms to rovers in the area and this correction is applied
- This is similar to WAAS

- Why is method #1 so great?
- (1) simple mathematics
- (2) limited data sent via communication
- Why is method#1 so bad?
- (1) The mathematics have no logical basis
- (2) The correction has no validation as "is this really helping".
- So we move to surveying's definition of differential GPS.
- (1) very complicated mathematical
- (2) very easy to validate especially when an "excess" of satellites exist.

- Survey grade uses "differential" GPS where more than one receiver is used
- Software solves for the difference in position between the multiple receivers by "differencing" the satellite information at two+ receivers.
- Differencing eliminates 99% of the systematic error in point positions

- Survey grade solutions go from
- (1) Autonomous – no use of multiple receivers to
- (2) float ambiguity solution – using differencing but have not confidently resolved the number of wavelength to
- (3) fixed ambiguity solution – the number of wavelengths have been resolved at a high confidence level resulting in 0.01-0.1 ft. quality
- Most surveying applications NEED FIXED AMBIGUITY SOLUTIONS!!!!!

- Why could prevent a fixed ambiguity solution?
- (1) distance between the two receivers (harder to solve for atmosphere)
- (2) obstructions (trees, buildings, etc.)

Multipath (very bad) is the bounce of signal off an object before it reaches the receiver

- The robotic total station is used where GPS cannot be used.

- Two ways to do differential GPS
- (1) post-processed – collect raw data and process in the office
- (2) Real Time Kinematic (RTK) – a base/network of bases and rover share data via radio or cell connection and data is processed in the field real time
- The early focus is post-processed GPS

- Fixed ambiguity means processing has successfully resolved the number of cycles in the used epochs. A fixed ambiguity solution is possible when the GPS data is "clean", i.e.,
- (1) the clock errors are correctable,
- (2) an appropriate atmospheric model has been resolved (hard when long distance between receivers),
- (3) no multipath exists (data bounces off objects to the antenna),
- (4) the satellite geometry is reasonable,
- (5) cycle slips (epochs with missing satellites) can be resolved, and
- (6) some form of redundancy exists in the number of epochs and the number of satellites observed in each epoch

- A processed vector is a 3-D X,Y,Z coordinate shift between two points.
- Native GPS provides the coordinate shift in geocentric coordinates, which is a Cartesian X,Y,Z system with its origin at the center of the ellipsoid that mathematically models the earth.
- The X,Y axes are in the equator with +X towards a longitude of zero degrees and +Y towards 90 degrees east.
- This makes the +Z axis point toward the north pole of the ellipsoid.

- Fortunately it is fairly easy to mathematically convert from geocentric coordinate shifts to shifts in latitude, longitude, and ellipsoid height (note GPS's vertical dimension is not elevation).
- If one point on the end of a vector has coordinates it is thus possible to compute the coordinates of the other end point of the vector.

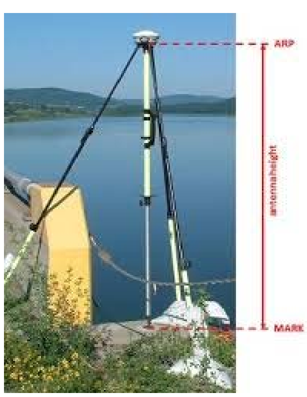
- Positional Tolerance
- The positional tolerance standard is normally a constant error plus a ppm error.
- As an example lets assume the positional tolerance standard is 0.01 m + 1/100000 (current standard in a state).
- A survey point has an error ellipse semi-major axis at 95% confidence of 0.03 m and it is 3000 m. from the nearest control point used in the least squares analysis.

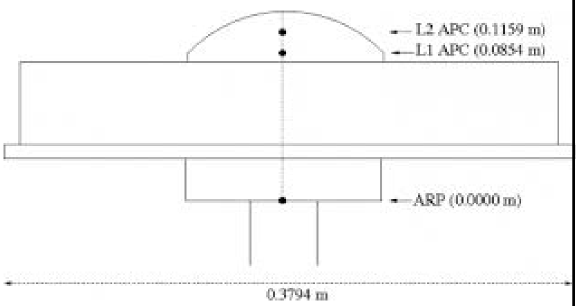
- Positional Tolerance
- The allowable positional tolerance is thus 0.01 + (1/100000)*3000 = 0.04 meters.
- Since the actual value of 0.03 m. is less than the standard of 0.04 m. the point passes positional tolerance.

- Public GPS Base Stations (allowing single receiver GPS)
- The national standard for public GPS base stations providing raw GPS data downloadable via the internet is the Continuously Operating Reference Stations (CORS) at www.ngs.noaa.gov/CORS.
- The MI DOT has been a standard for public GPS base stations

- A good time to cover antenna offsets
- If one does a conventional field survey with 2 m. fixed height bipods and the same antennas the antenna offset and H.I. is “not required” as they are the same at all points.
- Similar to cutting one ft. off a Philadelphia rod. + BS – FS gives the same results whether the ft. is there or not.
- Using CORS you will be mixing antenna types!!!!!
- Modern software has all antenna types and their offsets stored.

- A Rinex file header should contain the correct antenna name which can be read by modern software which will then apply the correct antenna offset.
- If the Rinex file header does not contain the antenna name a user must input this manually to software.
- Everything in H.I. is based on ARP – the Antenna Reference Position





- In the 2011 realization (aka adjustment) NGS moved from relative antenna calibrations to absolute antenna calibrations.
- From http://mycoordinates.org/gps-antenna-from-relative-to-absolute/
- Knowing Phase Center Variations (PCVs) is especially important in case different antenna types are used at the end points of a baseline. Mixing antennas usually happens in GPS regional and permanent networks like national networks, IGS and EPN. An uncalibrated antenna will certainly introduce errors that combined with other error sources result in significant erroneous point estimations, growing on long baselines (Mader 1999, Fotiou and Pikridas 2006).

- **Relative calibration**
- The relative phase center variation models are based on the assumption that the Alan Osborne antenna type AOAD/M_T has been approved of being the “Zero” antenna. This antenna type forms a standard with elevation dependent variations set to zero referring to a mean fixed offset. PCVs for a calibrating antenna can be determined using short-baseline field measurements (Rothacher et.al., 1995). Thus for each antenna type correction values were adopted relative to the external or mechanical antenna reference point (ARP, MRP). A database of relative calibrated antenna types has been generated with free access to everyone. The drawback is that the corrections are dependent on the zero/reference antenna and that PCVs at low elevations are not reliable due to the increment of noise and multipath in measurements below 10 degrees (Mader 1999).

- Combining GPS with other space-geodetic techniques becomes difficult in case of unmodeled systematic errors due to improper GPS antenna calibration models.
- As a consequence scale differences have been seen in GPS reference frames.
- Due to the above mentioned disadvantages relative models can no longer satisfy the increasing accuracy requirements.

- **Absolute calibration**
- The absolute calibration antenna models have been developed by the Geo++ company located in Garsben – Germany and a group of researchers from the University of Hannover (Wübbena et al. 2000, Völksen and Menge 2002). Absolute antenna offsets and PCV values are determined by means of a robotic system which include azimuthal values and elevations down to 0◦. The robot carries out fast rotations on different axes increasing the efficiency of the method. An advantage of this technique is the determination of a 3D offset and PCVs from 0◦ to 90◦ elevation angles with high precision and accuracy. Moreover the whole process takes place in an almost multipath – free environment. A complete set of absolute PCVs for the known tracking antennas is nowadays available.

- Calibration at NGS is described in (see robot arm below)
- http://www.ngs.noaa.gov/ANTCAL/docs/NGSantcalprocedures.pdf

- On-Line Processing User Service (OPUS-S and OPUS-RS)
- Several years ago NGS created this free service at www.ngs.noaa.gov/OPUS. A user is able to upload a dual frequency Rinex file and Opus-S will process this data relative to the nearest three CORS stations, and thus compute some basic statistical analysis based on the quality of the processing and the comparison of the solutions from the three distinct CORS stations. NGS requires a minimum of 2 hours of observational data (OPUS-S). Recently NGS has also provided rapid static OPUS (designated OPUS-RS) that is designed for data sets of 15 minutes to two hours.

- NGS has also provided rapid static OPUS (designated OPUS-RS) that is designed for data sets of 15 minutes to two hours.
- A different mathematical algorithm was implemented for shorter sessions, and up to 9 CORS stations are used if they fit the distance and geometry requirements of OPUS-RS.
- Thus it is possible to obtain survey accurate coordinates with a single dual frequency receiver, a long observation, and processing via OPUS.
- With OPUS-RS and reasonable availability of CORS stations in your area the observation time can be dramatically shortened.
- The limit is it is for dual frequency data only.
- OPUS does not use Glonass – boo!!!!!!

- Input to OPUS
- (1) Browse to the Rinex file
- (2) Select an antenna
- (3) Input an H.I.
- (4) Input an email address
- Sadly OPUS does not read antenna type and H.I. from the Rinex file

- Example OPUS-S output
- NAV FILE: brdc2670.14n OBS USED: 7550 / 7954 : 95%
- ANT NAME: TPSGR3 NONE # FIXED AMB: 39 / 41 : 95%
- ARP HEIGHT: 2.000 OVERALL RMS: 0.011(m)
- REF FRAME: NAD_83(2011)(EPOCH:2010.0000) IGS08 (EPOCH:2014.7302)
- X: 1646650.459(m) 0.002(m) 1646649.593(m) 0.002(m)
- Y: -4215192.766(m) 0.003(m) -4215191.354(m) 0.003(m)
- Z: 4479538.109(m) 0.004(m) 4479538.129(m) 0.004(m)
- LAT: 44 54 2.06051 0.004(m) 44 54 2.09825 0.004(m)
- E LON: 291 20 16.54773 0.001(m) 291 20 16.53438 0.001(m)
- W LON: 68 39 43.45227 0.001(m) 68 39 43.46562 0.001(m)
- EL HGT: 13.647(m) 0.004(m) 12.506(m) 0.004(m)
- ORTHO HGT: 38.318(m) 0.012(m) [NAVD88 (Computed using GEOID12A)]

- NGS says for quality “rules of thumb”
- (1) 70%+ of observations should be used – the more than three times the average residual identifies data to be rejected
- (2) More than 70% fixed ambiguities
- (3) Root mean square (average residual) should be of the coordinate quality you wish to obtain
- (4) The numbers next to Latitude longitude ellipsoid hgt. are “peak to peak” errors – the largest coor. difference in the solutions from the three base stations – a great form of data quality analysis

- Currently in surveying we use the NAD_83(2011)(EPOCH:2010.0000)
- Reference frame not the IGS08 (EPOCH:2014.7302) though it will be adopted in approximately 2022. IGS08 reflects the changes in location of the center of the ellipsoid that the international geodesy community has accepted since 1983.

- OPUS-RS example output
- SOFTWARE: rsgps 1.37 RS53.prl 1.99.2 START: 2014/09/24 11:43:10
- EPHEMERIS: igu18113.eph [ultra-rapid] STOP: 2014/09/24 13:32:35
- NAV FILE: brdc2670.14n OBS USED: 7092 / 12798 : 55%
- ANT NAME: TPSHIPER_LITE NONE QUALITY IND. 41.05/ 80.81
- ARP HEIGHT: 2.000 NORMALIZED RMS: 0.429

- REF FRAME: NAD_83(2011)(EPOCH:2010.0000) IGS08 (EPOCH:2014.73021)
-
- X: 1642406.210(m) 0.013(m) 1642405.344(m) 0.013(m)
- Y: -4211370.000(m) 0.023(m) -4211368.589(m) 0.023(m)
- Z: 4484658.839(m) 0.025(m) 4484658.859(m) 0.025(m)

- LAT: 44 57 56.27839 0.005(m) 44 57 56.31614 0.005(m)
- E LON: 291 18 19.62686 0.010(m) 291 18 19.61344 0.010(m)
- W LON: 68 41 40.37314 0.010(m) 68 41 40.38656 0.010(m)
- EL HGT: 16.796(m) 0.034(m) 15.658(m) 0.034(m)
- ORTHO HGT: 41.444(m) 0.036(m) [NAVD88 (Computed using GEOID12A)]

- UTM COORDINATES STATE PLANE COORDINATES
- UTM (Zone 19) SPC (1801 ME E)
- Northing (Y) [meters] 4979178.037 144343.050
- Easting (X) [meters] 524088.670 284652.866
- Convergence [degrees] 0.21585856 -0.13748400
- Point Scale 0.99960713 0.99990290
- Combined Factor 0.99960450 0.99990027

- US NATIONAL GRID DESIGNATOR: 19TEK2408879178(NAD 83)

- NGS recommends
- (1) Observations used is > 70%
- (2) The two quality indicator numbers are > 3 – great > 1 – ok and < 1 suspect. The first is from the network (CORS) stations only adjustment and the 2nd is from the rover included adjustment.
- (3) The normalized rms is similar to a standard error of unit weight so < 1 suggests the data is better than the reasonable GPS error estimate assigned to it.

- (4) The numbers next to Latitude longitude ellipsoid hgt. are coordinate one-sigma standard errors. A best fit coordinate is computed and the differences from it from the 9 (or less) used CORS stations are used to compute a standard deviation.

- I sometimes get this from OPUS

- FILE: ddd0924m.tps OP1411656428578

- 2005 NOTE: The IGS precise and IGS rapid orbits were not available
- 2005 at processing time. The IGS ultra-rapid orbit was/will be used to
- 2005 process the data.
- 2005
- 6009 The OPUS-RS solution for the position of the rover has
- 6009 failed to converge after 5 iterations. This could be due to
- 6009 especially noisy data (among other reasons). If you really need
- 6009 a position for this station, you might try another data set.

- But I got great results downloading the Rinex from the nearest CORS station and processing in my office vector baseline software!!!!!!

- How can this be????
- (1) OPUS is extremely picky and expects incredibly clean data.
- (2) Office vendor software is developed for typical survey field conditions that will contain noisy data due to obstructions. Office vendor software does a better job of finding the cleanest (fewest cycle slip) satellites and using them
- Or is my office software doing great because it used Glonass and Opus did not????

- Other on-line processing options
- From http://gpsworld.com/a-comparison-of-free-gps-online-post-processing-services/
- processing services are:
- CSRS-PPP: Canadian Spatial Reference System, Natural Resources Canada
- AUSPOS: Geoscience Australia
- GAPS: University of New Brunswick
- APPS: Jet Propulsion Laboratory
- SCOUT: Scripps Orbit and Permanent Array Center (SOPAC), University of California, San Diego
- magicGNSS: GMV
- CenterPoint RTX: Trimble Navigation

- Conclusions of the article
- **Conclusion**
- The similarity of results between all of the services I processed is amazing. That they differ only by millimeters demonstrates the robustness of the algorithms and processes they use.
- The difference between AUSPOS, RTX, GAPS, OPUS and CSRS-PPP solutions are negligible. For important positioning projects, it undoubtedly makes sense to use them all.
- For locations in the United States, OPUS and RTX return NAD83-2011 framed results. Only OPUS returns derived orthometric heights using GEOID12A. While OPUS has more provenance than the other services, it is easy enough to submit important observations to multiple services as a reality check for important positions.

- But I neglected to tell you he was processing 24 hr. long data sets so things are probably a little on the optimistic side for production!

- Precise Point Positioning (PPP) instead of differential (you must get bored hearing me blab about this)
- http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=en
- This requires initially getting a user name and password but the service is free.
- The antenna type and H.I. is read from the header of the Rinex file
- Single frequency is allowed, Glonass is processed, and kinematic is allowed.

- Sounds too good to be true?
- In two hours PPP and OPUS are very similar for dual frequency data.
- PPP slowly deteriorates faster than OPUS-RS for shorter observation times
- Single frequency using PPP seems to be 5-10 times less accurate than dual frequency for the same observation time

Precise Point Positioning: Is the Era of Differential GNSS Positioning Drawing to an End?

Chris RIZOS, Volker JANSSEN, Craig ROBERTS and Thomas GRINTER, Australia

- Available at
- https://www.fig.net/pub/fig2012/papers/ts09b/TS09B_rizos_janssen_et_al_5909.pdf

High-performance (i.e. high-accuracy and high-productivity) RT-PPP has been demonstrated, both in a commercial sense (Trimble's RTX) and by researchers (QZS testing). However, CORS network densities similar to those for RTK/NRTK-GNSS techniques are required. While the provision of real-time IGS products and the finalisation of industry-agreed data formats will give a significant boost to RT-PPP, the challenge of transmitting such data to user receivers remains. Furthermore, it is debateable that RT-PPP will ever challenge RTK/NRTK-GNSS techniques *on the grounds that it requires less or no CORS infrastructure*. The results so far suggest that the reduction in CORS infrastructure is not significant if "network-based" PPP techniques are used. Paradoxically, CORS networks will play a large role in providing the corrections required to achieve RT-PPP results with centimetre-level accuracy. Because the need for CORS networks will not disappear, the authors contend that while PPP will be a useful addition to the GNSS "toolkit", DGNSS-based techniques and services will still be a popular user option for many years to come because the justification for the establishment of CORS has *not* been weakened by recent developments in PPP.

- Finally almost to real time
- Kinematic GPS (post processed)
- The traditional concept is a moving receiver is located relative to a receiver on a known point.
- Thus every epoch at the rover is an individual position.
- Very short epoch intervals are used especially when the moving receiver is in an airplane with the intent of determination of camera exposure position for a photogrammetric mission.

- Kinematic GPS (post processed)
- Today usually integrated with Inertial Measuring Unit (IMU) which measures the orientation in 3-D of a moving unit
- The accelerometer of the IMU integrated twice allows computation of coordinate change in between GPS epochs
- IMU real time can be used to help GPS find satellites
- For information on Kinematic GPS/IMU/CORS/PPP processing see
- http://www.applanix.com/ (a Trimble company)

- Real Time Kinematic (RTK)
- In this operation the processing has been moved to the field in a real time environment.
- A radio link was traditionally the mechanism for transmitting raw GPS data to a central processing source (usually at the rover GPS receiver).
- While software generically processes in kinematic fashion in RTK the positions while the receiver in motion are rarely stored, and when the user defines the receiver is at a point it can begin averaging individual epoch solutions.
- The success of RTK is maintaining lock (fixed ambiguity) while moving between points, and if lock is lost (changes to a float solution) if in an open area the software attempts to regain a fixed ambiguity solution as soon as possible.

- RTK
- The idea of RTK is to have GPS be useable in open areas in the same way a total station would be used, as field coordinates can be generated for topographic purposes and stakeout can be performed.
- Point and chain attribution would follow the same logic as total station type collection, and alignments can be read for route survey computations.
- The collected points are available for any type of coordinate geometry computation.

- RTK
- RTK obviously computes vectors, and coordinates are derived from the vectors.
- Thus vectors can be used from RTK in any network adjustment just as they are in post-processed GPS.
- The beauty of the RTK solution to control surveying is that rover point occupation times can be minimized because you know instantaneously when you have a fixed ambiguity solution, instead of collecting data for a set time and hoping the solution is suitable when you process it in the office.

- RTK
- To create redundancy a RTK base station can be moved and the rover can visit previously observed points again.
- If a surveyor has 2 bases, one can collect information sequentially from the two bases by switching the rover between the radio frequencies/channels of the bases, but one should realize as discussed before this data will be quite dependent in nature as opposed to a later occupation of the point by a rover.
- Likewise multiple rovers can operate from one base if they are all operating on the same frequency.

- RTK
- The biggest limit of the first generation of RTK technology was the maximum distance between a base and a rover.
- A lower end 3 watt radio worked up to 1.5 miles and the 30 watt radios on good days worked up to a distance of 4 miles.
- The radio frequency could receive interference from another radio based system and thus become dysfunctional.
- Lastly, a person usually had to watch a base station to prevent it from being stolen, but they was little survey productivity from this person while "babysitting" a base station.

- RTK
- The latest alternative to radio communication between a base and a rover is a cell modem.
- This is similar to a cell phone that is totally dedicated to data transmission.
- A base is assigned an Internet Protocol (IP) address, and the rover simply logs into the base via the cell technology.
- The distance between base and rover now becomes a limit of required accuracy due to the distance and not the communication link between the base and rover.
- The longer distances can also create longer times required for fixed ambiguity solutions to be realized.
- This is obviously a monthly charge for the cell modem transmission similar to what occurs for a cell phone, and you need coverage for data transmission in your work area by your cell provider.

- Permanent base station RTK
- The base station in RTK has always been a source of ire, as it must be “watched” by someone so it is not stolen, but there is little productivity from that person during this period.
- Obviously if one could eliminate the need for an RTK base a purchase of simply a rover would reduce cost.
- Most agencies and vendors have addressed this with the implementation of cell modem based permanent RTK base stations.
- The limit is obviously the distance from the permanent base to the job site as longer distances limit accuracy and the time it takes to obtain fixed ambiguity solutions.

- Permanent base station RTK
- Some agency or academic base stations offer free access, while vendor base stations may be password protected and/or require a monthly charge to access.
- One amazing item is all vendors have adapted standard RTK formats (RTCM or CMR+) so it is possible to have a base station from vendor “X” communicating to a rover receiver from vendor “Y”.
- Thus what is Rinex in the post-processed world converts to usually RTCM in the real-time world.

- Permanent Base station RTK
- A permanent base station does not require a cell modem, instead it requires an internet connection.
- The data is available via the Internet and the data is accessed by a user through a cell or internet connection.
- Thus if the world was free wireless there would be no need for cell connection for GPS. But we know the cell companies would not like that!!!!!

- Permanent Base station RTK
- Everything in the cell/internet world is an IP (Internet Protocol) address. You are accessing base station information simply by accessing a computer or network's IP address.
- IP addresses are normally replaced today by web type alphanumeric addresses which basically hides the numerical IP address
- Port assignments are like subdirectories. Under one IP address can be multiple ports that support many individual base stations or data types
- Under an IP address to a user port addresses usually turn into a list of mountpoints available to a user

- Permanent Base station RTK
- The definition of mountpoint could be as simple as a list of every base station in a network.
- Usually a "select closest base station" allows an automatic selection to eliminate incorrectly selecting a base station far away.
- Mountpoint can segregate from single base vs. multiple base solutions.
- Mountpoint can segregate data type (GPS+Glonass, GPS only, RTCM and version, CMR+, lower accuracy differential corrections

- Everything is managed in a real time base station network (RTN) by Ntrip.
- From Wikipedia, the free encyclopedia
- 'Networked Transport of RTCM via Internet Protocol' (**Ntrip**) is a protocol for streaming differential GPS (DGPS) data over the Internet in accordance with specification published by RTCM. **Ntrip** is a generic, stateless protocol based on the Hypertext Transfer Protocol HTTP/1.1 and is enhanced for GNSS data streams.
- **Ntrip** was developed by the German Federal Agency for Cartography and Geodesy (**BKG**) and the Dortmund University Department of Computer Science. **Ntrip** was released in September 2004 as "RTCM Recommended Standards for Networked Transport of RTCM via Internet Protocol (Ntrip), Version 1.0". The current version of the protocol is Version 2.0 with Amendment 1, June 28, 2011.
- **NTRIP** is an open standard protocol. The protocol can be freely download from **BKG** and there is an open source implementation available from software.rtcm-ntrip.org.

- NTRIP protocol is a variant of Hypertext Transfer Protocol (HTTP) the protocol used for transmitting data back and forth through websites and is familiar to everyone from website addresses where it always precedes the address with the familiar http:// symbol.
- NTRIP is a protocol that is a subset of HTTP and is designed specifically for GNSS networks.
- It allows for a much greater throughput of data and, provides security features through user logins and password checking.
- NTRIP is the protocol used to transfer data throughout most GNSS networks from the base stations to the networks server software and the user in the field.
- The data is streamed through all the mountpoints of a Real Time Network using NTRIP.
- The user in the field seldom needs to know anything about NTRIP except that it is a setup option within the survey controller setup choices.
- When there is a choice of NTRIP or something else, the user needs to choose NTRIP, not something else.

- True RTN solutions
- To enhance the solution vendors presently offer solutions that utilize multiple permanent bases in a “best fit” solution.
- Vendors utilize the raw data at the bases to estimate what the raw data would look like at a base receiver at your job site – hence it is called a “virtual reference base station” - VRS.
- The concept has been thoroughly tested by estimating what interpolated raw data would look like at a permanent base derived from neighbors, and comparing it to the actual raw data.
- By placing the VRS next to you (the rover) the error due to varying atmosphere at base and rover has been eliminated.

- Alternative #1 to VRS
- FKP – instead of placing a virtual base station on the job site interpolation is used to resolve what corrections should be applied to a field unit

- Alternative (2) to VRS
- The most significant amount of work to alternatives to VRS is in direct solution of vectors from multiple bases to a rover and performing a field “adjustment/best fit” of the vectors. It could be thought of as a real time OPUS type solution.
- Most of the alternative to VRS solutions now produce one vector from the closest base station that is a product derived from multiple base stations.
- This is called “MAX” by Leica

- RTN solutions
- In all the three types of RTN solutions the RTCM being produced is partially processed instead of truly raw satellite information
- The base stations in the network are being used to correct the raw data in an area to what it would look like if satellite position errors, atomic clock errors, and atmosphere errors have been eliminated
- The real time atmosphere correction is in its infancy stage compared to the other corrective models.

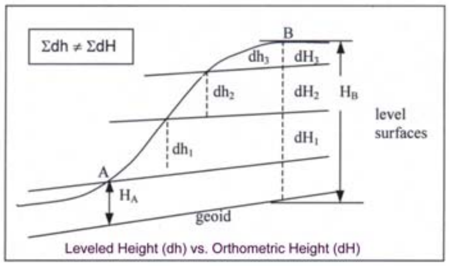
- Going rogue
- https://www.navcomtech.com/navcom_en_US/products/equipment/cadastral_and_boundary/starfire/starfire.page
- Starfire is a John Deere implementation of real-time precise ephemeris modeling that sends information to users via John Deere communication (not John Deere GPS) satellites
- Thus it is using a series of base stations to create a precise ephemeris that is sent to users
- The claim is 5 cm. accuracy real-time.

- Trimble joins the dark side!
- http://www.trimble.com/agriculture/correction services/centerPointRTX-satellite.aspx
- The new Trimble® CenterPoint™ RTX™ correction service delivers GPS or GNSS enabled, repeatable 1.5" (3.8 cm) corrections via satellite directly to your receiver. CenterPoint RTX works with the built-in receiver in your existing Trimble TMX-2050™ display, FmX® integrated display, CFX-750™ display, or AG-372 GNSS receiver. Eliminating the need to purchase additional radio hardware or cellular data plans.

- http://www.trimble.com/positioning-services/pdf/whitepaper_rtx.pdf
- **RTX Positioning: The Next Generation of**
- **cm-accurate Real-Time GNSS Positioning**

- The RTX (**R**eal **T**ime e**X**tended) positioning solution is the technology resulting from the employment of a variety of innovative techniques, which combined provide users with cm-level real time position accuracy anywhere on or near the earth's surface.
- This new positioning technique is based on the generation and delivery of precise satellite corrections (i.e. orbit, clocks, and others) on a global scale, either through a satellite link or the internet. The innovative aspects of the new solution can be divided into different categories, which directly relate to the areas that have represented different levels of limitation on making global high accuracy positioning possible. These areas are:
- a) Integer level ambiguities derivation;
- b) Real-time, high accuracy satellite corrections generation;
- c) Data transmission optimization;
- d) Positioning technology.

- This far with no mention of elevations or geoids!!! Or did I mean orthometric heights?



- Fortunately one has to have a level line of more than 100 miles in length before orthometric height differential compares to elevation difference by more than 0.01 meters.
- So for all practical purposes for engineering design work orthometric height difference equals elevation difference.

- Geoid is defined at NGS as

  There have been many definitions of the "geoid" over 150 years or so. Here is the one currently adopted at NGS:

  geoid: The equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level Even though we adopt a definition, that does not mean we are perfect in the realization of that definition. For example, altimetry is often used to define "mean sea level" in the oceans, but altimetry is not global (missing the near polar regions). As such, the fit between "global" mean sea level and the geoid is not entirely confirmable. Also, there may be non-periodic changes in sea level (like a persistent rise in sea level, for example). If so, then "mean sea level" changes in time, and therefore the geoid should also change in time. These are just a few examples of the difficulty in defining "the geoid".

- The real deal
- "Since 2009, NGS performed the National Adjustment of 2011. This significantly affected the ellipsoid heights of data all around the country. Since the GPSBM's are determined from the difference between the ellipsoidal (NAD 83) and orthometric (NAVD 88) heights, a change in one height type changes the control value and thus affects the hybrid geoid. "
- Meaning don't mix portions of 2011+ data with things prior to it. Especially because we went from relative to absolute antenna calibrations which changed all ellipsoid heights, and therefore had to change the geoid model.

- Historically
- (1) Geoid90 - This was the first available model available on a personal computer. The GEOID90 model was computed on December 19, 1990 using nearly 1.5 million terrestrial and ship gravity values. By comparing the GEOID90 model with combined GPS and leveling, the GEOID90 has roughly a 10-cm accuracy (one sigma) over length scales of 100 km. Better accuracy is seen over shorter lengths.

- (2) Geoid93 - The GEOID93 model was computed on January 26, 1993 using over 1.8 million terrestrial and ship gravity values. By comparing the GEOID93 model with combined GPS and leveling, the GEOID93 has roughly a 10-cm accuracy (one sigma) over length scales of 100 km. Better accuracy is seen over shorter lengths. At transcontinental spacings the accuracy of GEOID93 will be governed by the accuracy of the underlying global geopotential model, OSU91A. In some locations of the country, long-wavelength errors in GEOID93 up to a 1 to 2 part-per-million level may occur. Because of better data quality and coverage, and better computational procedures, GEOID93 possesses better accuracy in mountains when compared to GEOID90.

- The 1st Hybrid!!!
- (3) Geoid 96 - The GEOID96 model was computed on October 1, 1996 using over 1.8 million terrestrial and marine gravity values. By means of NAD 83 GPS ellipsoidal heights on NAVD 88 benchmark data (700 points), plus known relationships between NAD 83 and the ITRF94 reference frames, a conversion is applied to generate the final GEOID96 geoid model. This conversion causes the GEOID96 model to be biased relative to a
- geocentric ellipsoid; but, this bias is deliberate. The GEOID96 model was developed to support direct conversion between NAD 83 GPS ellipsoidal heights and NAVD 88 orthometric heights. When comparing the GEOID96 model with GPS ellipsoidal heights in the NAD 83 reference frame and leveling in the NAVD 88 datum, it is seen that GEOID96 has roughly a 3-cm accuracy (one sigma) in the regions of GPS benchmark coverage.
- In those states with sparse (150km+) GPS benchmark coverage, less point accuracy may be evident; but relative accuracy at about a 1 to 2 part-per-million level,or better, should still be obtained.

- (4) Geoid 99 - The GEOID99 model is known as a hybrid geoid model, combining gravimetric information with GPS ellipsoid heights on leveled bench marks (6169 points). The GEOID99 model was developed to support direct conversion between NAD 83 GPS ellipsoidal heights and NAVD 88 orthometric heights. When comparing the GEOID99 model with GPS ellipsoidal heights in the NAD 83 reference frame and leveling in the NAVD 88 datum, it is seen that GEOID99 has roughly a 4.6 cm absolute accuracy (one sigma) in the regions of GPS on Bench Mark coverage. In those states with sparse (150km+) GPS on Bench Mark coverage, less point accuracy may be evident; but relative accuracy at about a 1 to 2 part-per-million level, or better, should still be obtained.

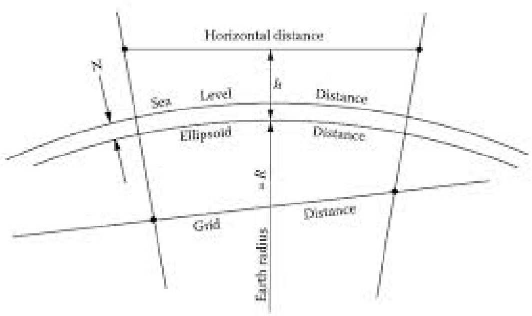
- 5-Geoid03 - The GEOID03 model is known as a hybrid geoid model, combining gravimetric information with GPS ellipsoid heights on leveled bench marks (14185 points). The GEOID03 model was developed to support direct conversion between NAD 83 GPS ellipsoidal heights and NAVD 88 orthometric heights. When comparing the GEOID03 model with GPS ellipsoidal heights in the NAD 83 reference frame and leveling in the NAVD 88 datum, it is seen that GEOID03 has roughly a 2.4 cm absolute accuracy (one sigma) in the regions of GPS on Bench Mark coverage. In those states with sparse (150km+) GPS on Bench Mark coverage, less point accuracy may be evident; but relative accuracy at about a 1 to 2 part-per-million level, or better, should still be obtained.

- 6-Geoid09 – Obviously a hybrid model that began with 20445 GPS benchmarks, though 1002 were rejected due to excessive errors in ellipsoid height, orthometric height, or indications of crustal movement as identified as being outside a 95% standard deviation. 12961 of these points were in the 48 contiguous states. 303 of these were rejected as not fitting within 95% confidence. The actual benchmarks used are listed at http://www.ngs.noaa.gov/GEOID/GPSonBM09/

- It is believed Geoid09 has a better long wavelength (long distance trends) than previous geoids, and that its terrain model (short wavelength) is dramatically improved. Note also Geoid09 is tied to ellipsoid heights that may have improved due to readjustment such as NSRS 2007. For example Florida had 1413 GPS benchmarks in Geoid09 and their respective fit is estimated to have a one sigma standard deviation of 1.5 cm. (see http://www.ngs.noaa.gov/GEOID/GEOID09BETA/tech.html) 1.3 million terrestrial and ship-borne gravity measurements are included in Geoid09. Not included was the new airborne gravity measurements that are part of the ongoing Grav-D project http://www.ngs.noaa.gov/GRAV-D/

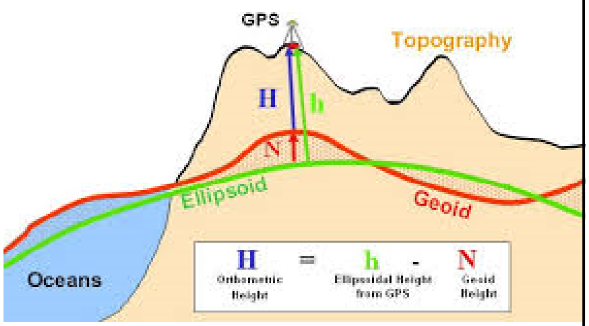
- 7-Geoid12a or Geoid12b (some errors were corrected in the original Geoid12) – This is the first geoid based on absolute instead of relative antenna calibrations. This changed antenna offsets from phase centers to the antenna reference point (ARP) slightly. Number of benchmarks remained approximately the same but a better fit to ellipsoid heights based on absolute antenna offsets enhanced the geoid model,

- The most significant work in Geoid12a occurred in the COnterminous United States (CONUS). For CONUS, there were 24,782 points with 911 rejected leaving 23,961. These were supplemented from the OPUS-database with 737 points of which 238 were rejected leaving 499. There were also 579 points in Canada with 5 rejected leaving 574. In Mexico, there 744 of which 497 were clipped since they were too far south and another 70 were rejected leaving 177. This brings a total of 26,932 points of which 1,721 were rejected or clipped and 25,211 retained for modeling GEOID12A.



Note - Within continental United States N is a negative value.

- Ellipsoid height to elevation
- (1) geoid model – a model of gravity converts globally
- (2) local model – the GPS base station is at a known elevation instead of a known ellipsoid height so differential works in elevation difference over a “small” area



- But what happens in 2022
- http://www.ngs.noaa.gov/GRAV-D/
- We join the rest of the world and accept the latest 0,0,0 for center of ellipsoid and start using coordinates on the right hand side of the OPUS page (currently IGS 08)
- The new vertical datum will be totally GPS and gravity (geoid) based because the new airborne gravimeter can collect so much data efficiently.
- Benchmarks in the ground will no longer be included as the model is not hybrid
- Our vertical datum will not include benchmarks!!!

- Simplest way to make ellipsoid height/geoid height fit existing benchmark
- (1) Compute the misfit at the benchmark
- (2) adjust all elevations by that misfit
- Great for a small area!
- But no real check as only one benchmark was used

- Multiple benchmarks in a network
- The misfit will be different at each BM
- DTM approach to “adjusting” for misfit
- (1) Think of each BM as a triangle node in a digital terrain model (DTM) where at each node is the correction at the BM
- (2) For every other station the correction is prorated linearly across DTM triangles
- Example BM 1 correction +.02 m, BM 2 correction -.01 m, unknown station is 1/3 dist. From BM1 to BM2
- Correction at unknown station will be +.01 as 1/3 from BM1 to BM2