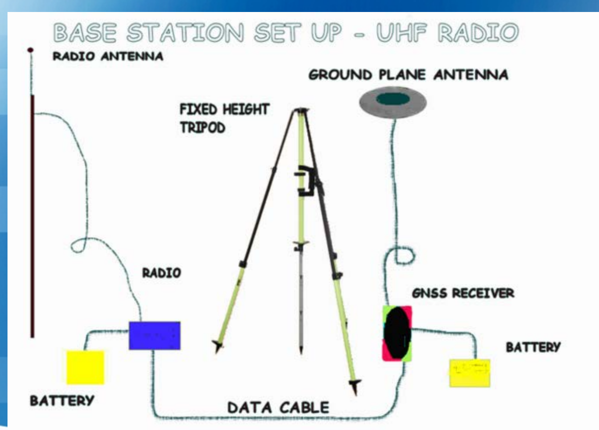
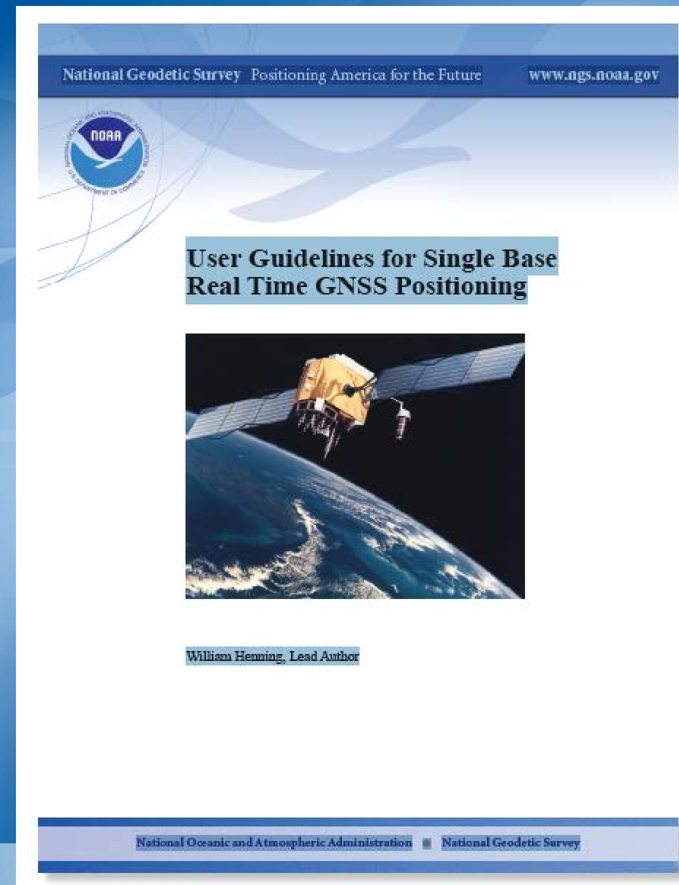
NGS WEBINAR NOVEMBER 9, 2011

REAL TIME GNSS POSITIONING BEST METHODS FOR THE FIELD




National Geodetic Survey Positioning America for the Future www.ngs.noaa.gov

User Guidelines for Single Base Real Time GNSS Positioning

William Henning, Lead Author

National Oceanic and Atmospheric Administration ■ National Geodetic Survey

Bill Henning
Geodesist, Prof.LS.

National Oceanic and Atmospheric Administration

THE IMPORTANCE OF INTELLIGENT RT FIELD WORK

- Multipath
- Position Dilution of Precision (PDOP)
- Baseline Root Mean Square (RMS)
- Number of satellites
- Elevation mask (or cut-off angle)
- Base accuracy- datum level, local level
- Base security
- Redundancy, redundancy, redundancy
- Part(s) Per Million Error (ppm) – iono, tropo models, orbit errors
- Space weather- sunspot numbers, solar maximum
- Geoid quality
- Site calibrations (a.k.a. Localizations)
- Bubble adjustment
- Latency, update rate
- Fixed and float solutions
- Accuracy versus Precision
- Signal to Noise Ratio (S/N or C/N0)
- Carrier phase solution
- Code phase solution
- VHF/UHF radio communication
- CDMA/SIM/Cellular TCP/IP communication
- WGS 84 versus NAD 83, or other local datums
- GPS, GLONASS, Galileo, Compass Constellations

THE CONTROL IS AT THE POLE!

WORKSHOP PLAN

INRODUCTION-CHANGE AS A WAY OF LIFE

↓

BACKGROUND- DATUMS, RTN vs SINGLE BASE

↓

HOW RT GNSS POSITIONING (RT) WORKS- BEYOND THE BLACK BOX

↓

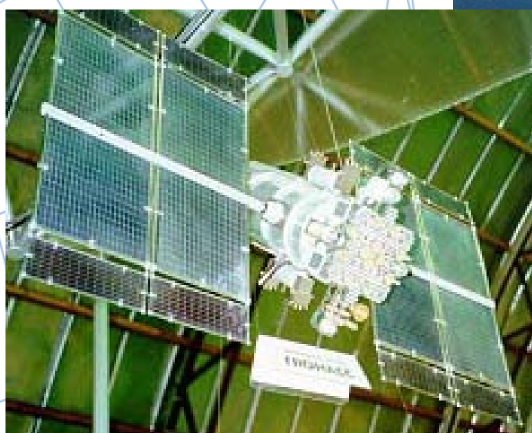
GEOMETRICAL & DISPERSIVE EFFECTS ON THE GNSS SIGNAL

↓

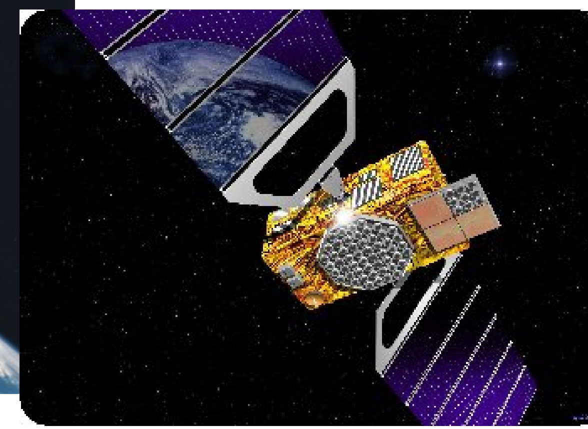
BEST METHODS FOR GNSS REAL TIME POSITIONING- A FIELD GUIDE

GNSS POSITIONING TECHNOLOGY- WHERE WE STAND NOW AND WHERE WE ARE HEADED

GPS



GLONASS



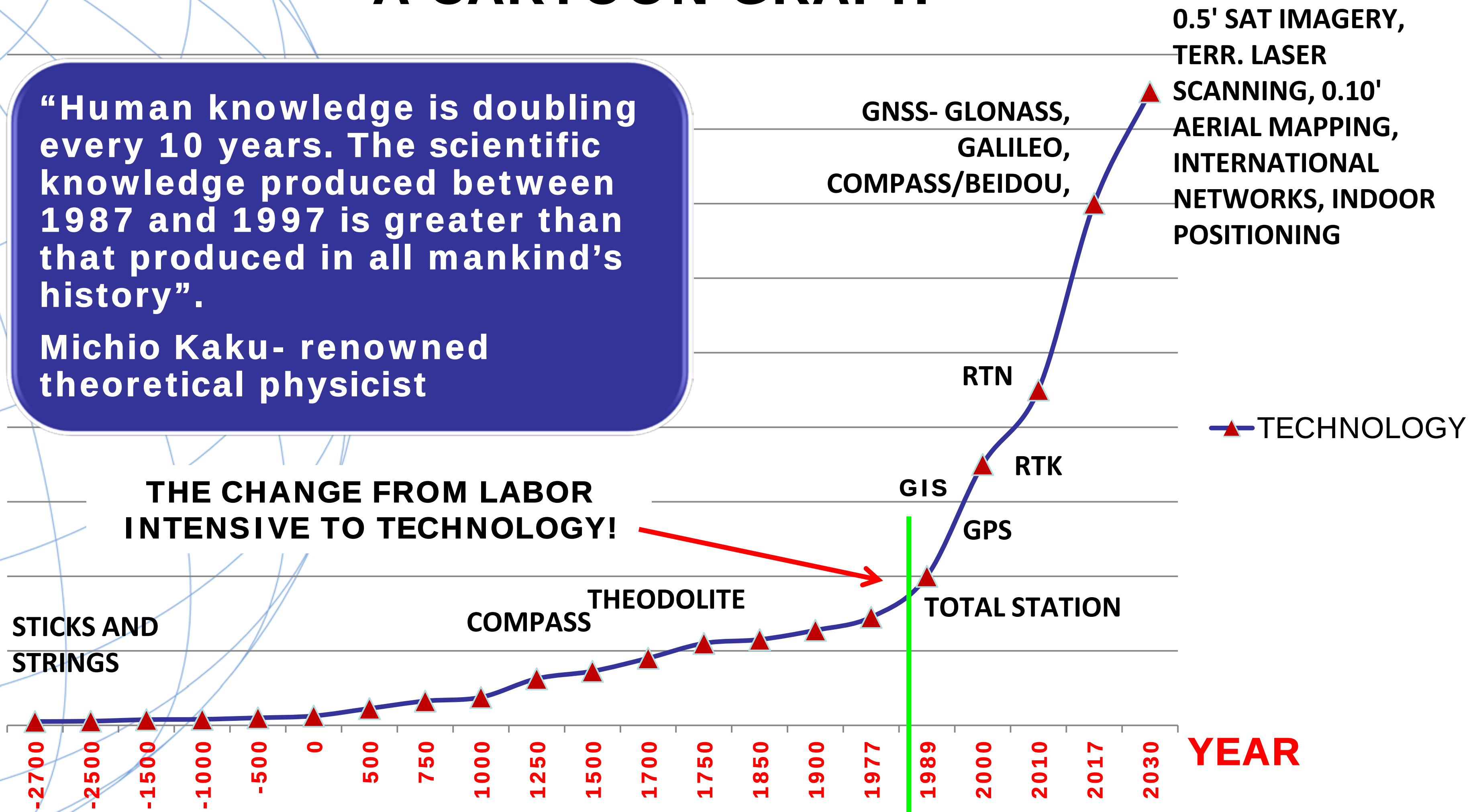
GALILEO

COMPASS (BEIDOU-2)

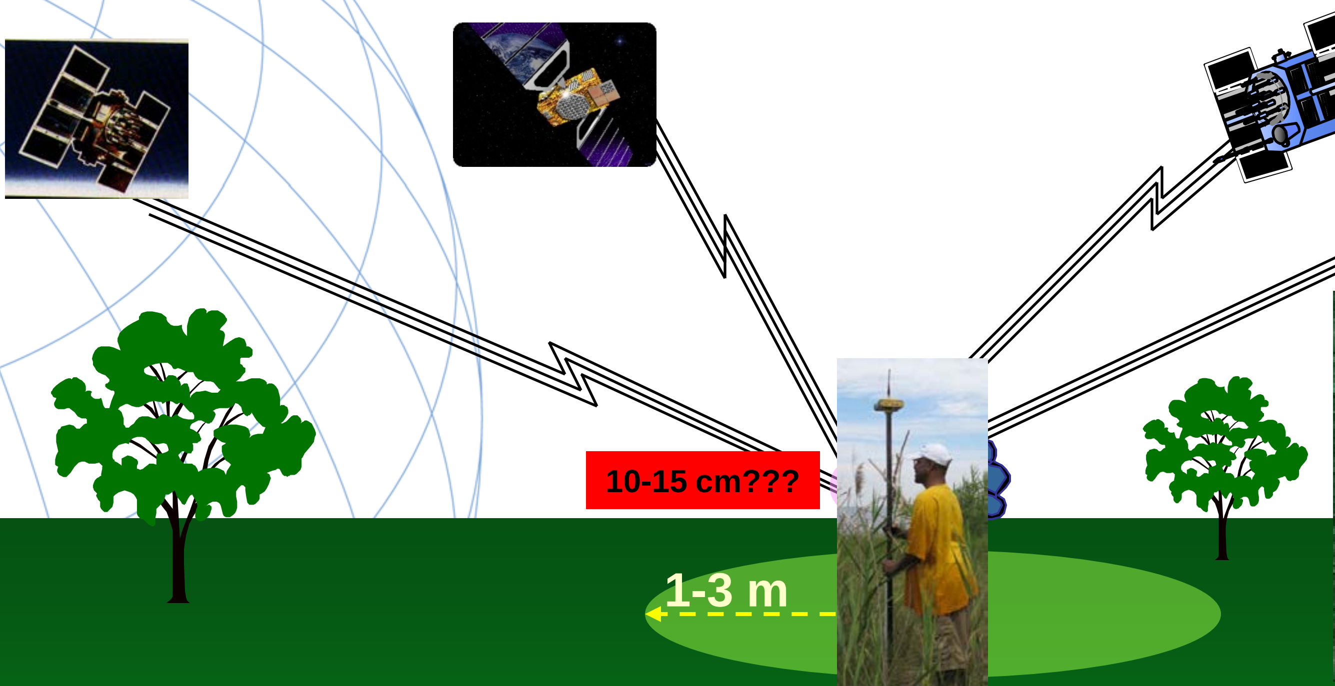
POSITIONING TECHNOLOGY- A CARTOON GRAPH

"Human knowledge is doubling every 10 years. The scientific knowledge produced between 1987 and 1997 is greater than that produced in all mankind's history".

Michio Kaku- renowned theoretical physicist



CHANGES IN GNSS



GPS:
- L2C
- L5 CARRIER
- New Code on L5
- L1C

GLONASS- FULL OPERATIONAL CAPABILITY 2011

EUROPEAN UNION - GALILEO

CHINA – COMPASS/BEIDOU

= 115 SATELLITES?

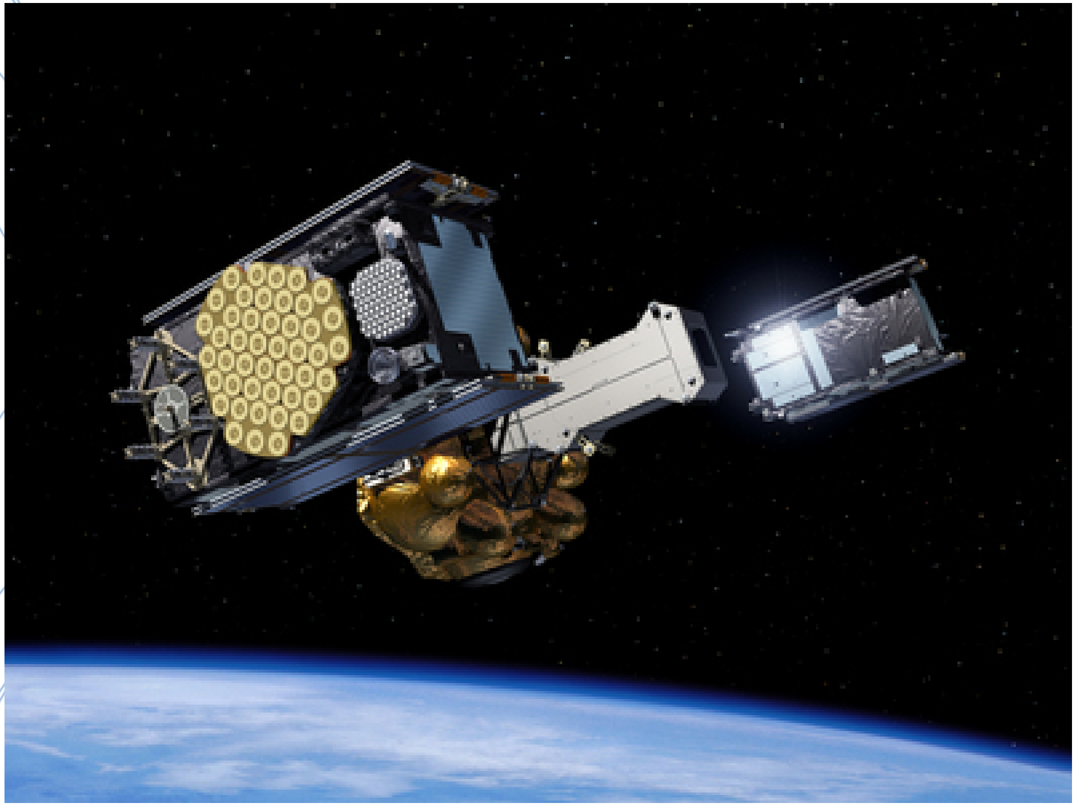
REGIONAL:
(JAPAN- QZSS FIRST LAUNCH 2010)
(INDIA – GAGAN)

BETTER RESISTANCE TO INTERFERENCE

FASTER AMBIGUITY RESOLUTION

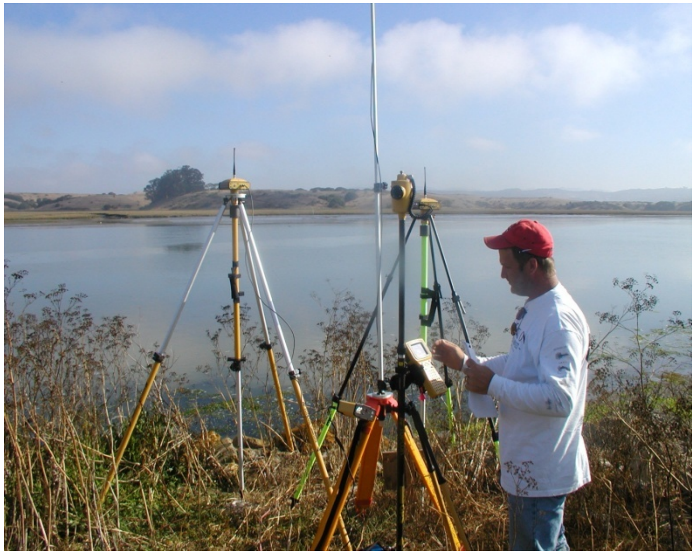
AUGMENTED CODE APPLICATIONS

GALILEO- OFF THE GROUND
OCTOBER 21, 2011

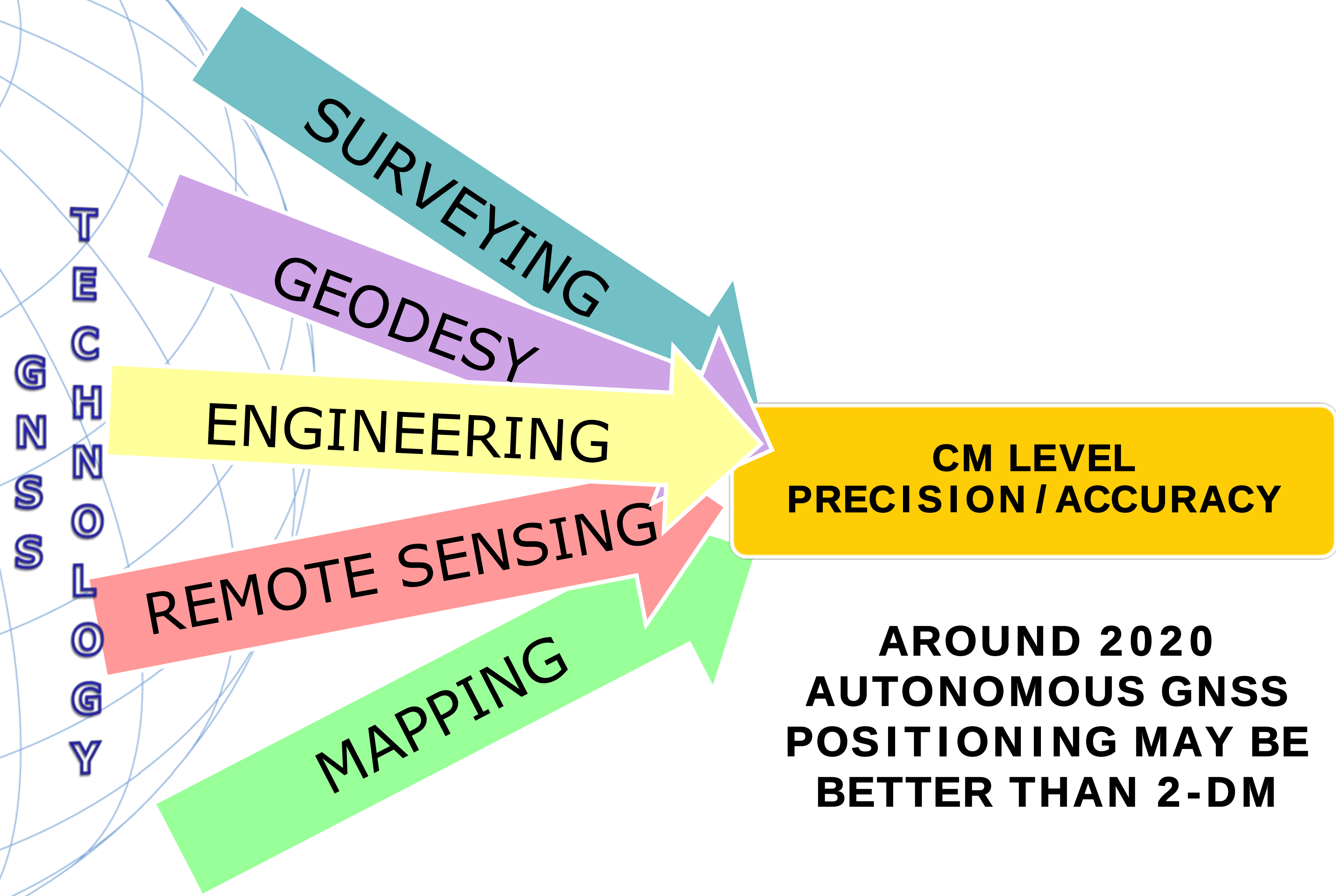


2 IOV SATELLITES, EUROPEAN SPACEPORT, FRENCH GUIANA, RUSSIAN SOYEZ ROCKET (SPUTNIK, YURI GREGARIN)

THE USE OF RTK- A CONFLUENCE OF TECHNOLOGY

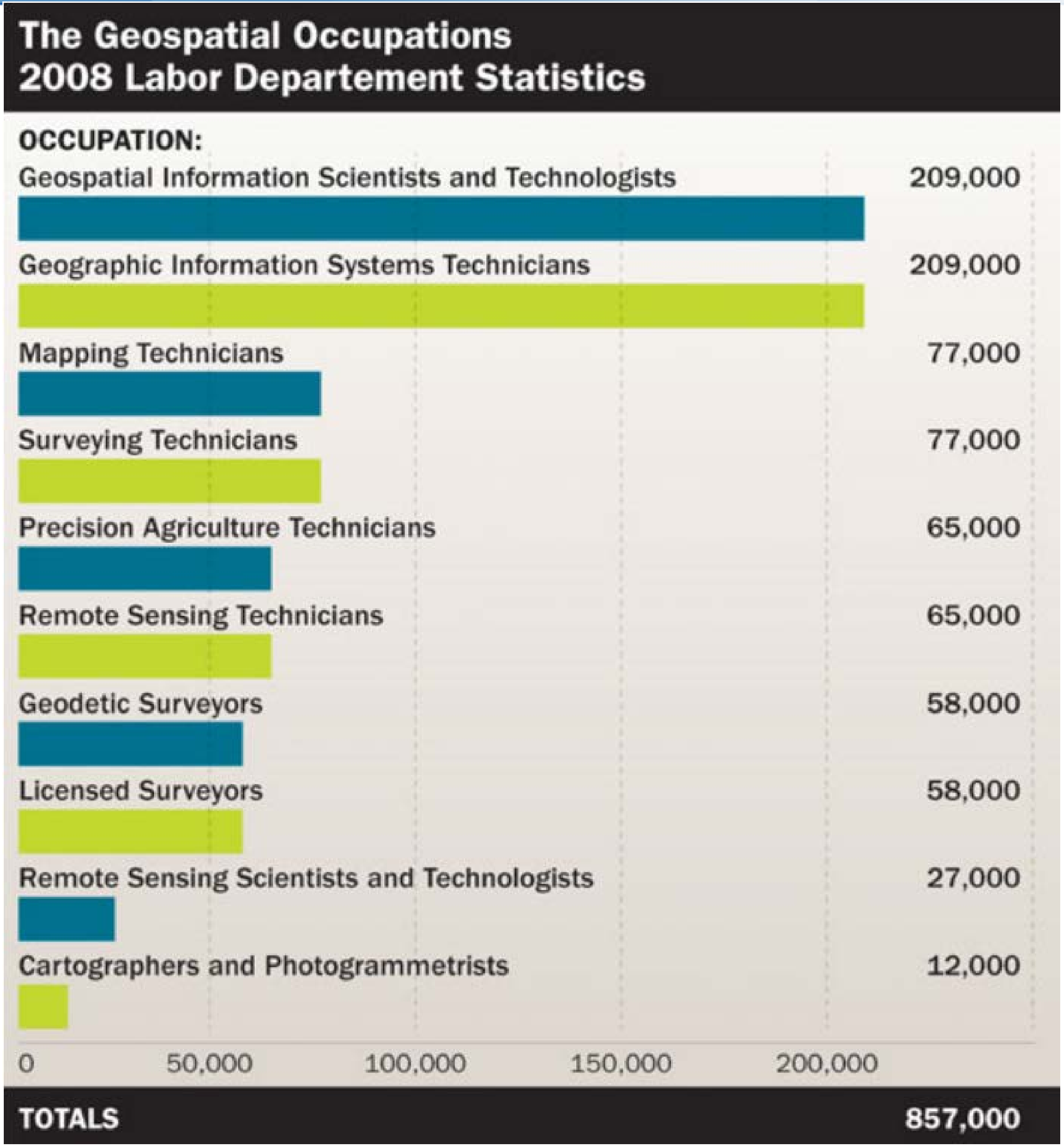


- INTERNET DATA VIA CELL TECHNOLOGY
- SOFTWARE/FIRMWARE ALGORITHMS
- GNSS HARDWARE
- SATELLITE CONSTELLATIONS
- SATELLITE CODES/FREQUENCIES



AROUND 2020 AUTONOMOUS GNSS POSITIONING MAY BE BETTER THAN 2-DM

GEOSPATIAL PROFESSIONALS



Graphic:
Jeffery N. Lucas, PLS, Esq.
POB Magazine
On-Line Article
September 28, 2011
www.POBonline.com

MULTI-YEAR CORS SOLUTION (MYCS) = NAD 83 (2011):

- BETTER ORBITS http://geodesy.noaa.gov/CORS/coords.shtml
- MORE TRUE VELOCITIES KNOWN (1200 STATIONS +/- WITH >2.5 YEARS OF DATA-OTHERS MODELED WITH HTDP)
- ABSOLUTE ANTENNA CALIBRATIONS
- BROUGHT TO A MORE CURRENT EPOCH (2002 to 2010)
- IMPLEMENTED SEPT 2011

PASSIVE CONTROL ADJUSTMENT TO MYCS:

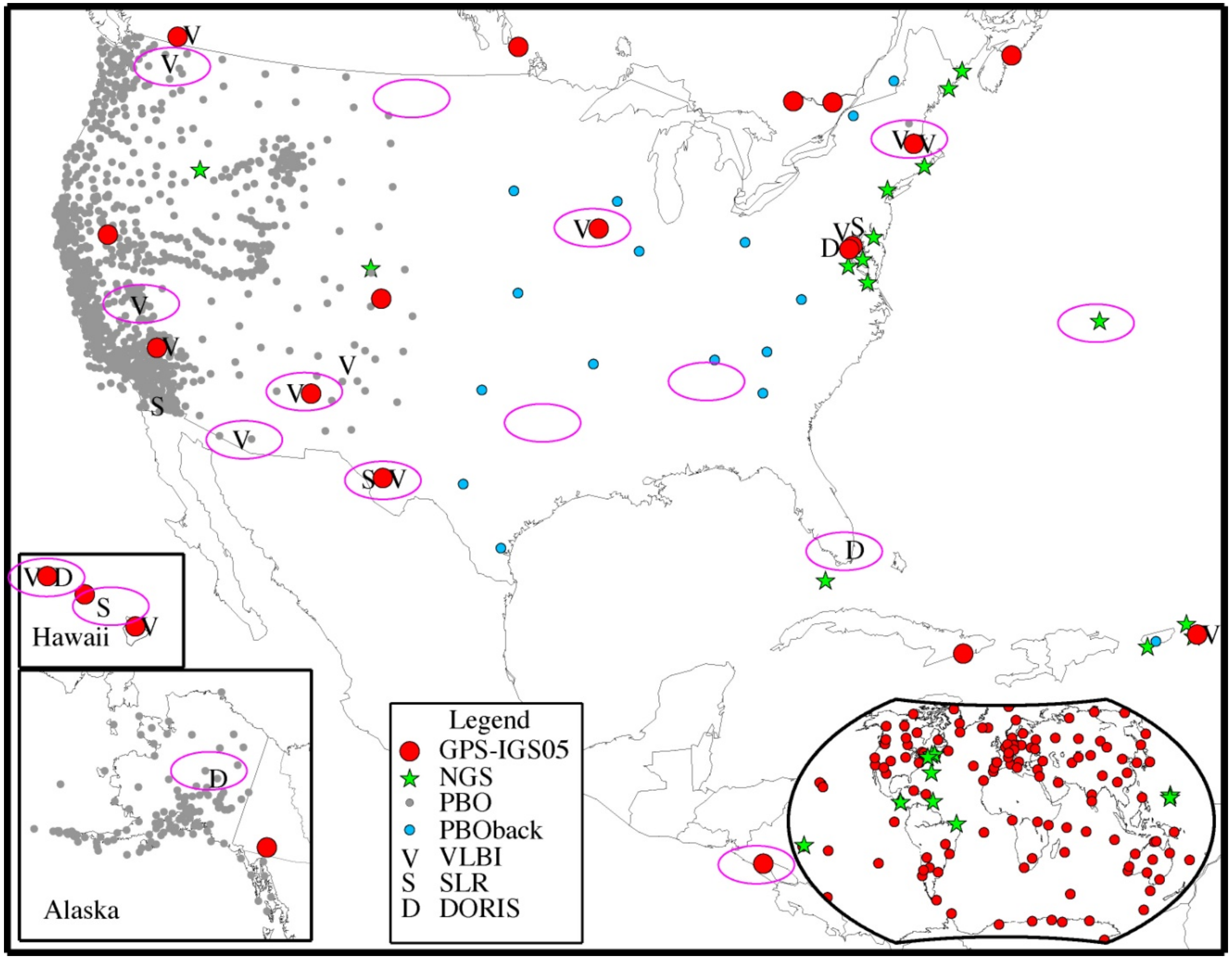
- ORIGINAL OBSERVATIONS!!
- NO VELOCITIES KNOWN (MODELED ONLY)
- NO RIGOROUS ADJUSTMENT
- 5000 GPS PROJECTS SIMULTANEOUSLY VIA "NETSTAT" TO 95% CONFIDENCE
- IMPLEMENTED EARLY CALENDAR YEAR 2012+/-
- WILL HAVE NETWORK & LOCAL ACCURACIES

NEW GEOMETRICAL DATUM 2022 +/-

FOUNDATION CORS

FEDERALLY OWNED/OPERATED BASE NETWORK = ULTIMATE TRUTH

- **Link to ITRF at sites co-located with VLBI, SLR, DORIS, then fill geographic gaps**



Possible sites = magenta ovals

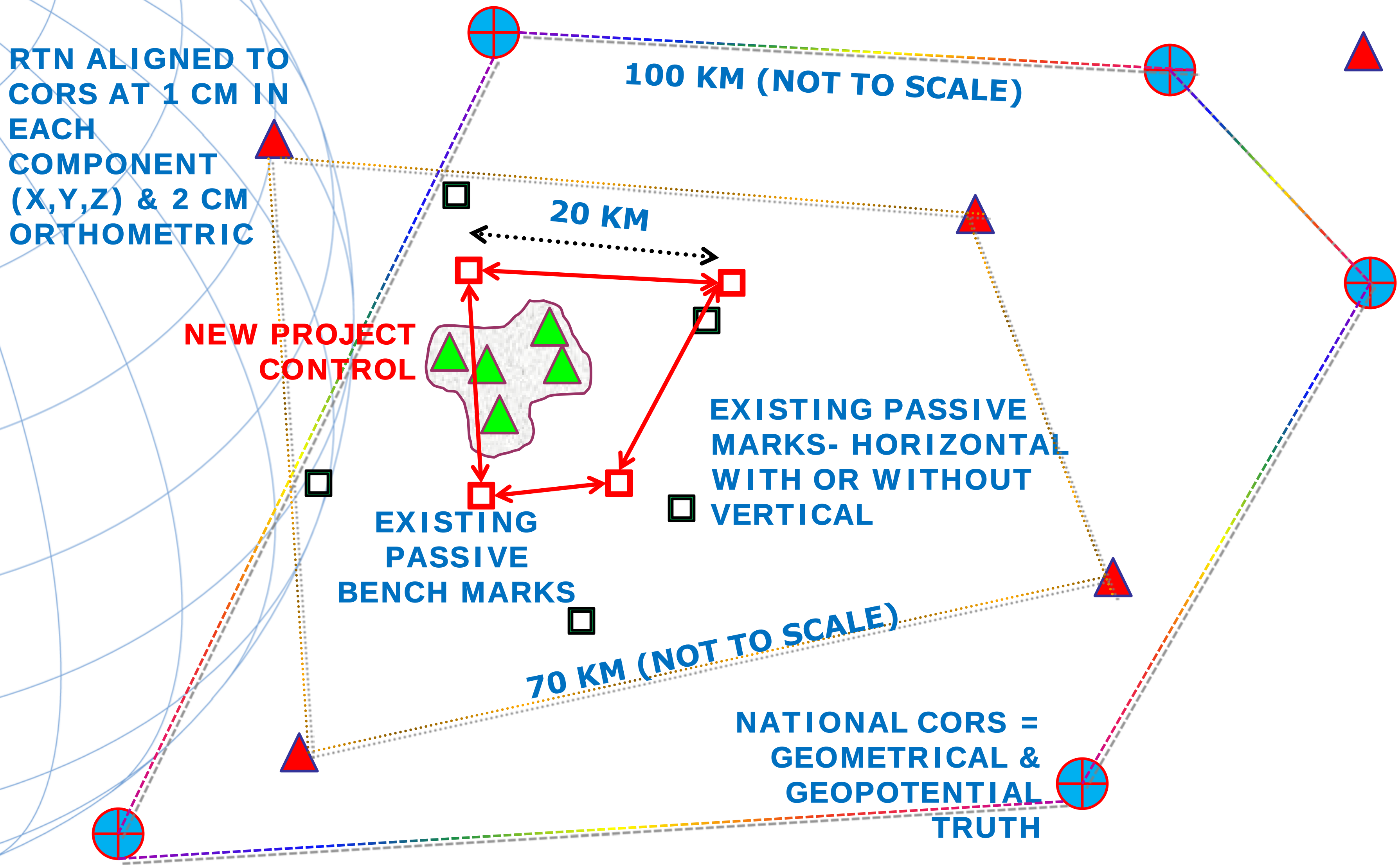
NEW NATIONAL VERTICAL DATUM 2022?

- A PURELY GRAVIMETRIC SURFACE
- BASED ON A HIGH RESOLUTION, 1 CM GEOID FROM GRAV-D PROGRAM
- ACCURATE TO 2 CM (ALLOWING FOR GNSS ERROR)
- ACCESSABILITY: BROUGHT TO A PROJECT SITE VIA ACTIVE REFERENCE STATIONS (NATIONAL CORS), DENSIFIED TO PROJECT ACCURACY NEEDS. (ALTERNATIVE: USE BMs PREVIOUSLY TIED TO THE DATUM-CAVEAT EMPTOR)

WHAT ABOUT THE PASSIVE MARKS?

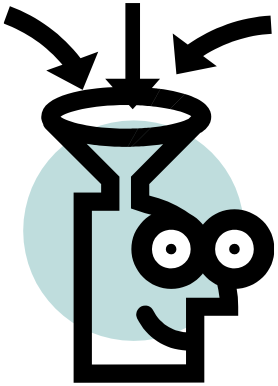
- **SECONDARY ACCESS** (USE AT YOUR OWN RISK)
  - PASSIVE MARKS THAT HAVE BEEN TIED TO THE NEW VERTICAL DATUM
  - NGS WILL PROVIDE A "DATA SHARING" SERVICE FOR THESE POINTS, BUT THEIR ACCURACY (DUE TO EITHER THE QUALITY OF THE SURVEY OR THE AGE OF THE DATA) WILL NOT BE A RESPONSIBILITY OF NGS
  - A CONVERSION WILL BE PROVIDED BETWEEN NAVD 88 AND THE NEW DATUM WHERE RECENT GNSS ELLIPSOID HEIGHTS EXIST TO PROVIDE MODERN HEIGHTS IN THE NEW DATUM

2022 NEW PROJECT CONTROL – ACCESS TO NSRS

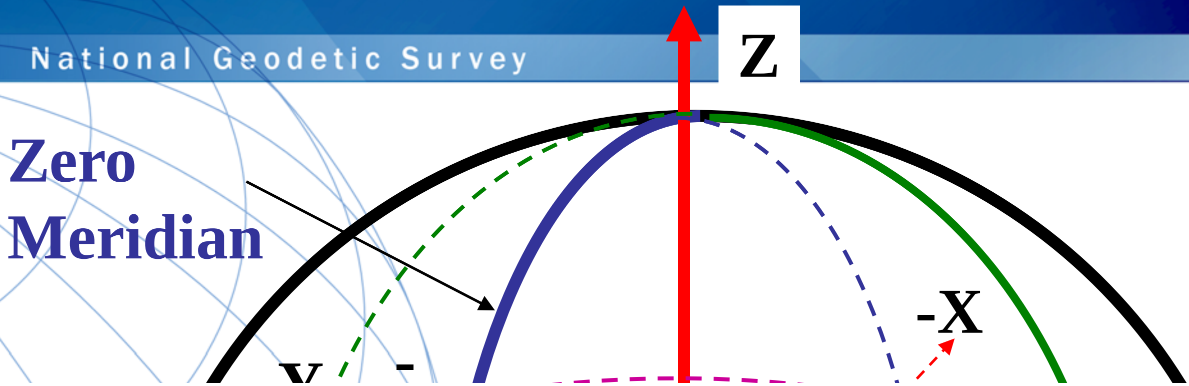


NECESSARY BACKGROUND

(BUT KNOWLEDGE DOES ≠ WISDOM)



KNOW YOUR DATUM / ADJUSTMENT / EPOCH



DATUM =
- ***SURFACE***
- **ORIENTATION**
- **SCALE**

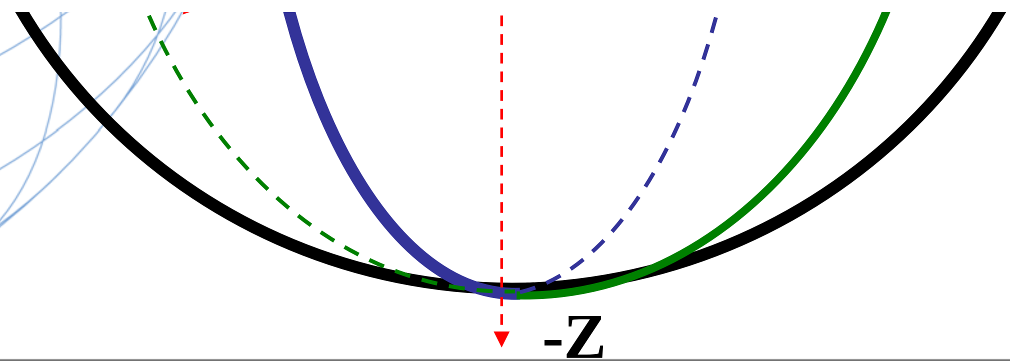
a = 6,378,137. m (exact by definition)

1/f = 298.25722210088 (to 14 significant digits by computation)

From these two numbers, any other desired constants of geometric geodesy may be derived. For example, to 14 significant digits:

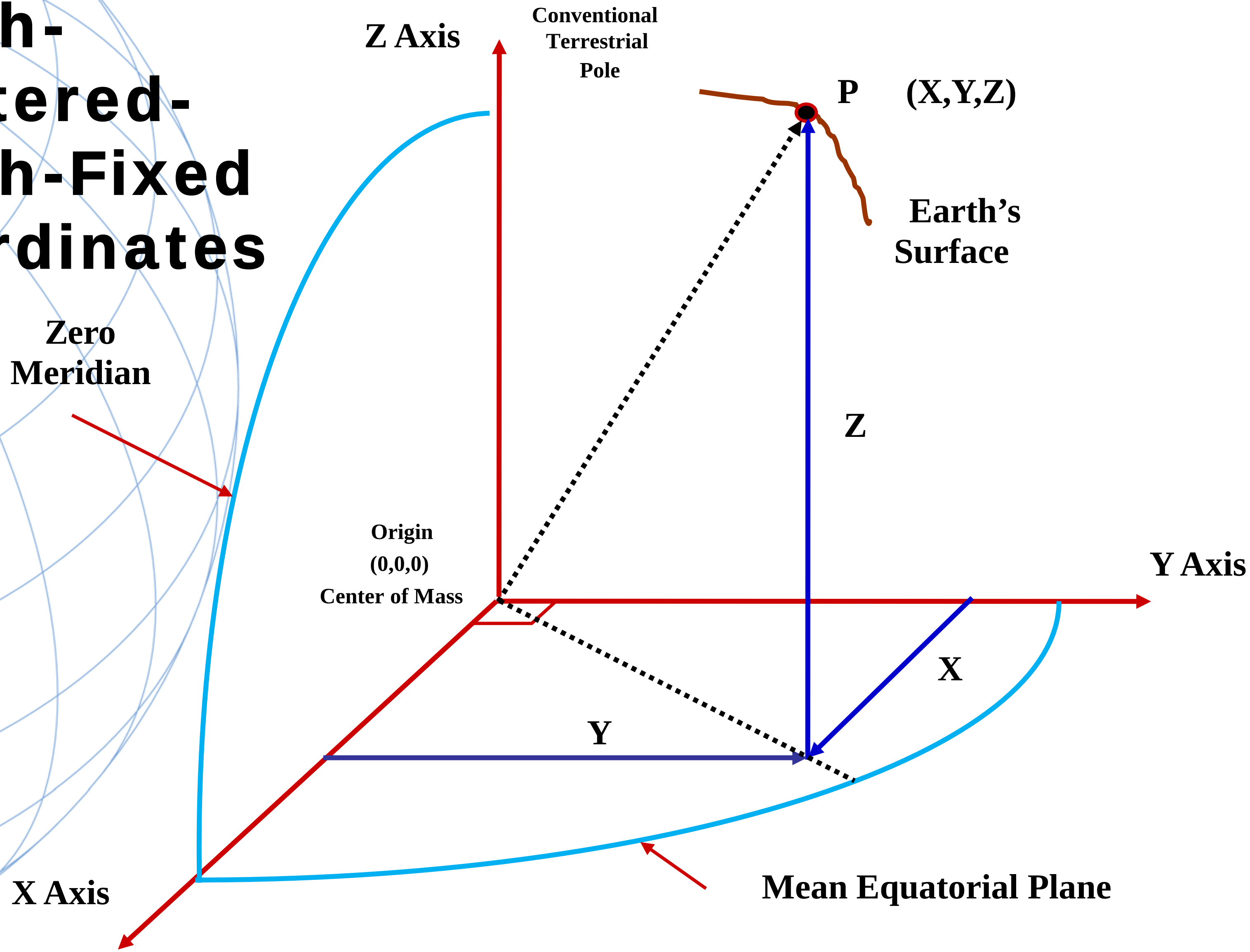
b = 6,356,752.3141403

e^2 = 0.0066943800229034.

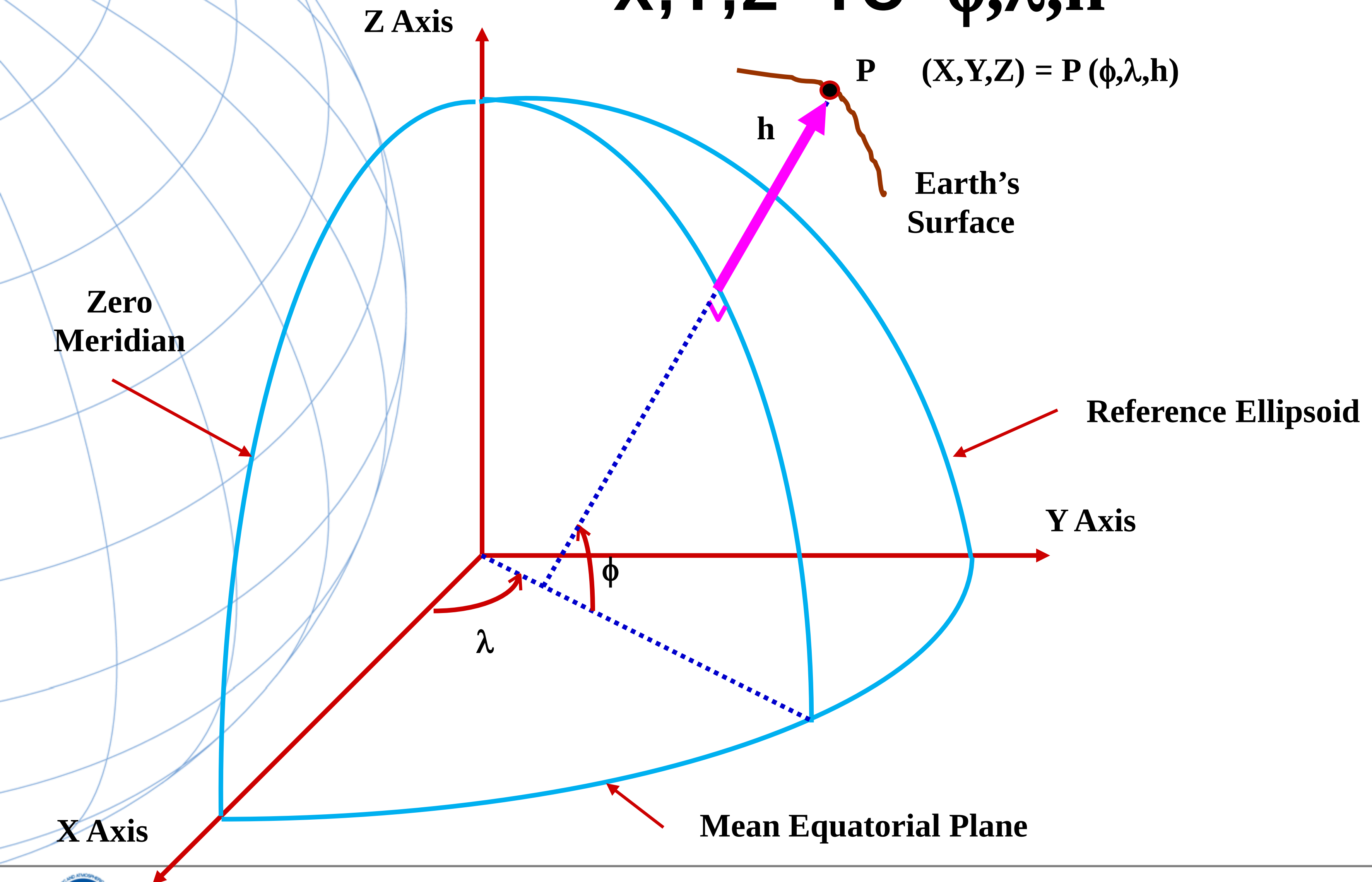


GPS POSITIONS ARE ECEF, XYZ IN THE WGS 84 DATUM (NOT NAD 83)

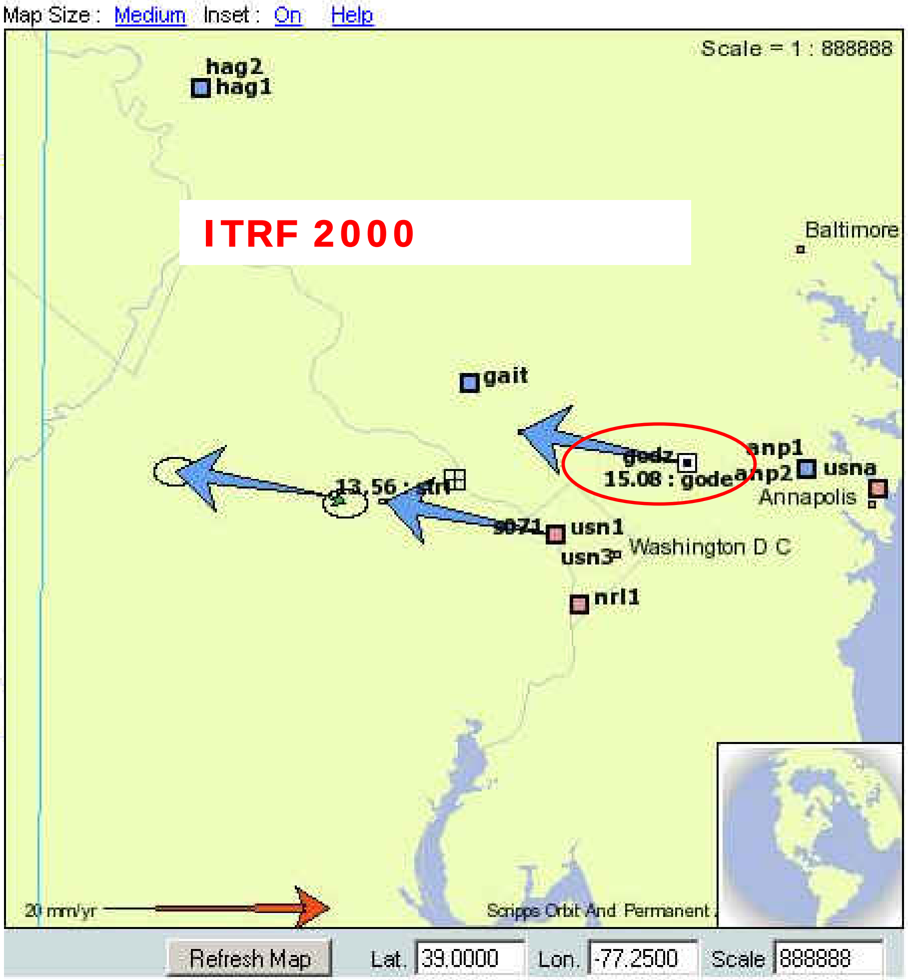
Earth-Centered-Earth-Fixed Coordinates

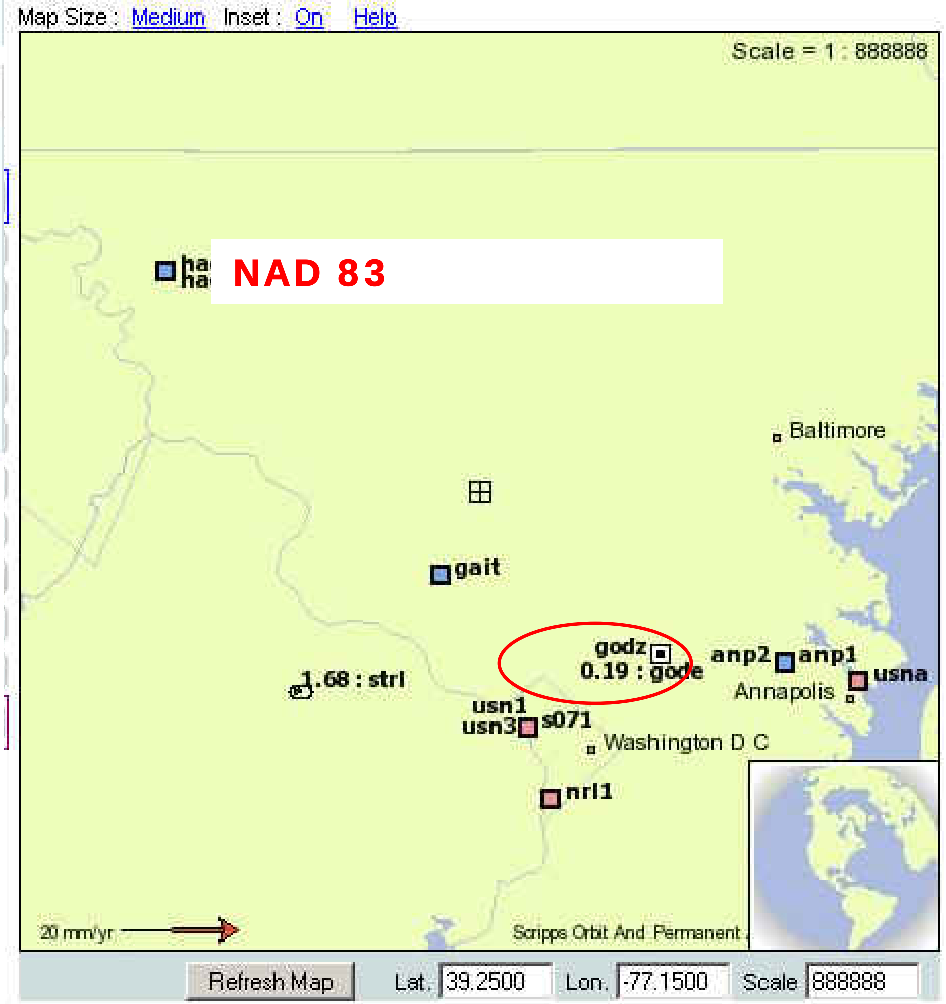


X,Y,Z TO ϕ,λ,h



SILVER SPRING, MD

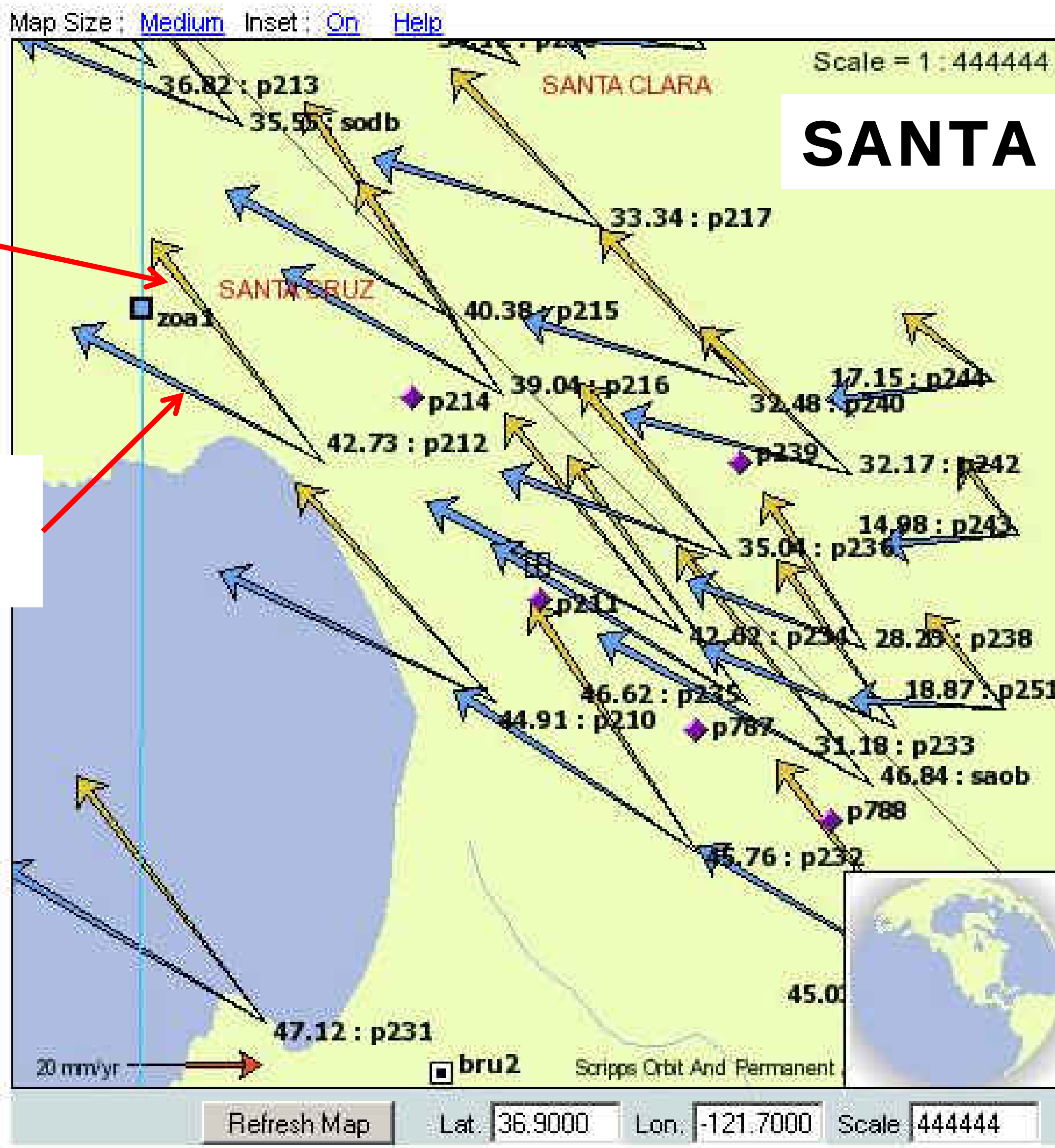




SANTA CRUZ, CA

NAD 83 VELOCITIES (GOLD)

ITRF 2000 VELOCITIES (BLUE)



GNSS TO ANY DATUM

- GNSS ECEF X,Y,Z (WGS 84 & PZ90)

→ NAD 83 (ϕ,λ,h) → SPC N,E,h

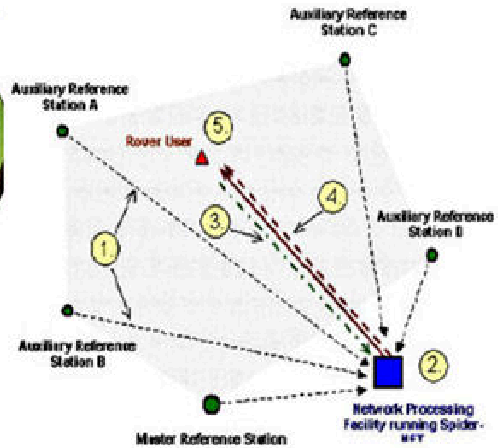
+ GEOID XX → = SPC N,E,H

OR

CALIBRATE TO 4-5 SITE POINTS IN THE DESIRED DATUM. THIS IS USED TO LOCK TO PASSIVE MONUMENTATION IN THE PROJECT AREA.

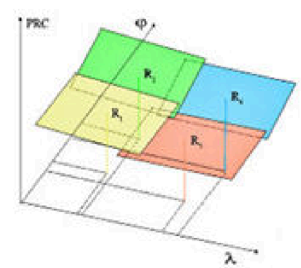
USING REAL TIME GNSS NETWORKS FOR POSITIONING

A



B

C



THE THREE BASE STATION OPTIONS FOR RT

<u>SINGLE-BASE</u> – PASSIVE MONUMENT. USER OPERATED. SPREAD SPECTRUM RADIOS (LINE OF SIGHT), UHF RADIOS (3-5 MILES), DATA MODEMS, CELL PHONES (UP TO 30 MILES)

<u>NETWORK SYSTEM</u> – PROVIDER OPERATED. DATA MODEMS, CELL PHONES

<u>SINGLE BASE</u> – ACTIVE REFERENCE STATION (24/7/365). USER OR PROVIDER OPERATED. DATA MODEMS, CELL PHONES

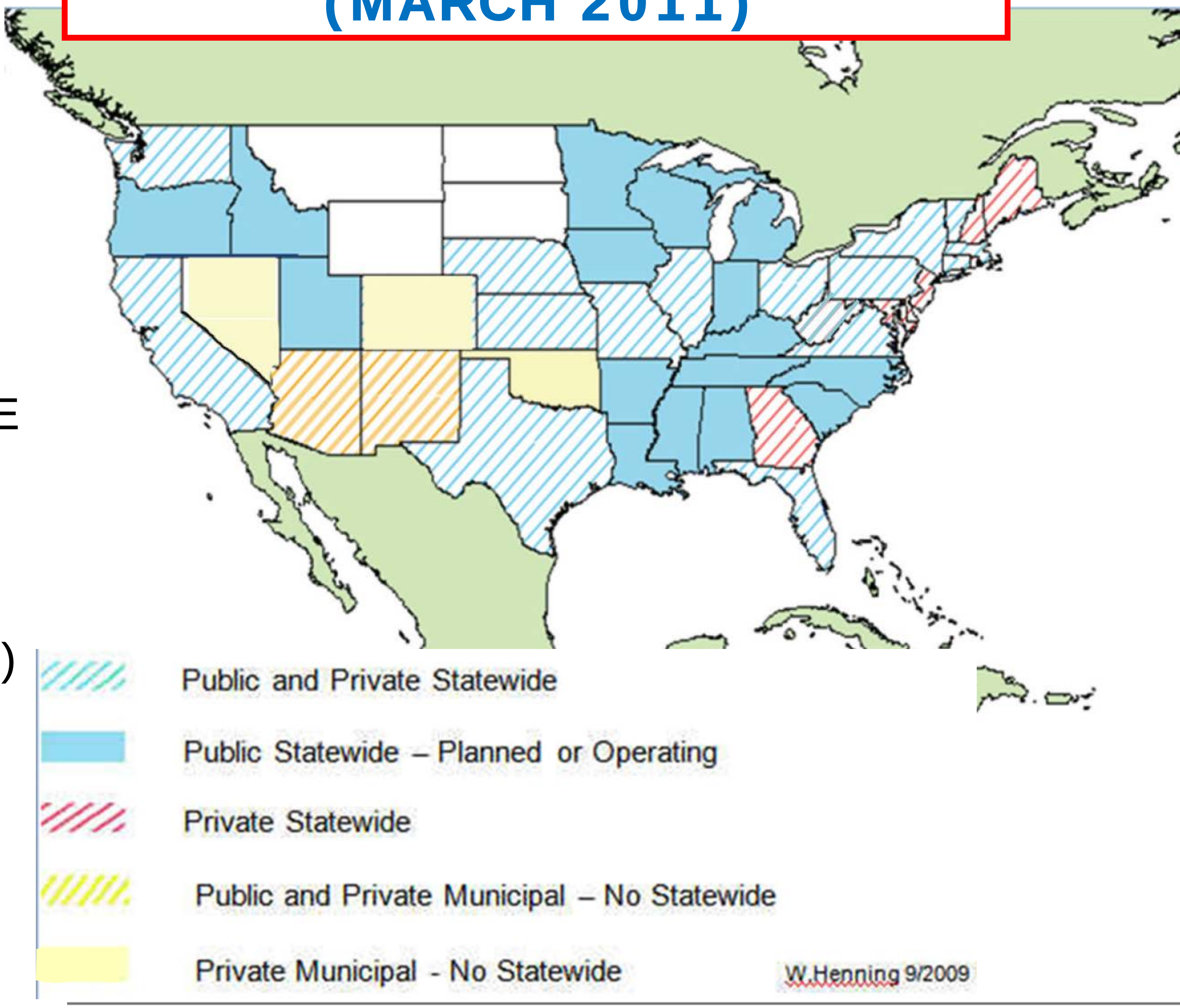
THE TECHNOLOGY SWEET SPOT

- SBAS: 2 M H, 6 M V, 0.3 M SMOOTHED H, CHEAP
- COMMERCIAL DGPS: FEW DM, $$
- USCG BEACON: METER+, CHEAP
- DIFFERENTIAL LEVELING: 2-4 CM, LABOR/TIME INTENSIVE, $$$
- GEODETIC LEVELING: mm, LABOR/TIME INTENSIVE, $$$$$
- USER BASE RTK: 2-4 CM H, 3-5 CM V, REQUIRES INITIAL INVESTMENT
- RTN: 3-4 CM H, 5-7 CM V, REQUIRES INITIAL INVESTMENT(BUT ½ OF RTK)
- AERIAL MAPPING: .10 M H, .20 M V, $$$
- LIDAR: 0.10 – 0.3 M V
- SATELLITE IMAGERY: 0.5 METER H RESOLUTION, 3 M LOCATION, $$$
- LOW ALTITUDE AERIAL IMAGERY: 2-4 CM H, 3-5 CM V, $$$
- TERRESTRIAL LASER SCANNING: PROJECT SITES ONLY, 0.015 M H, 0.02 M V, REQUIRES INITIAL INVESTMENT

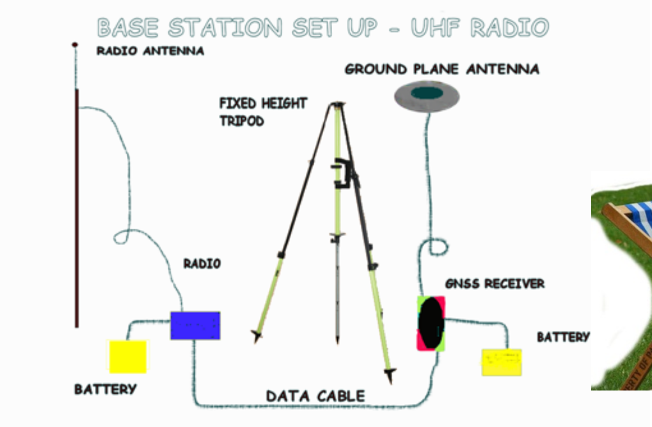
MAJOR RTN IN THE USA
(MARCH 2011)

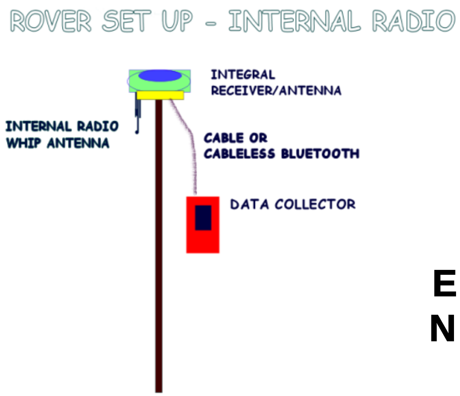
≥200 RTN WORLDWIDE
≥107 RTN USA
≥37 DOT

- ACADEMIC/SCIENTIFIC
- SPATIAL REFERENCE CENTERS
- VARIOUS DOTS + MACHINE GUIDANCE
- COUNTY
- CITY
- GEODETICSURVEYS(NC,SC)
- MANUFACTURERS
- VENDOR NETWORKS
- AGRICULTURE
- MA & PA NETWORKS



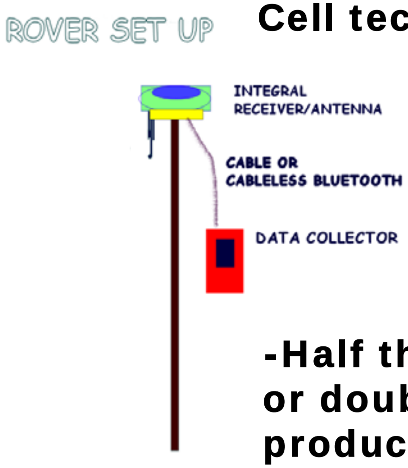
RTK vs. RTN





RTK

Plus:
Easy alignment to the NSRS
No ppm (1ST ORDER) ERROR
Extended range
Homogeneous Data
Easy datum updates



Cell technology

RTN

- **-Half the equipment or double the production**
- **-No monument reconnaissance / recovery**
- **- No set / break down time**
- **-No base baby sitting**

SO – WHAT CAN I EXPECT FROM An RTN?

MOST RTN PRODUCE "GOOD" HORIZONTAL VALUES – TO A FEW CM. OUR HORIZONTAL SYSTEM IS BASED ON ACTIVE REFERENCE STATIONS (NGS CORS), AS ARE THE RTN STATIONS.

BECAUSE ORTHOMETRIC HEIGHTS ('ELEVATIONS') ARE BASED ON PASSIVE MONUMENTS WITH NAVD 88, THE RTN USER SHOULD, FOR THE MOST PART, CONSTRAIN THE PASSIVE MARK VALUES IN A LOCALIZATION.

CHOOSE THE RTN WITH A BUSINESS MODEL THAT BEST FITS YOUR NEEDS.

USERS CONCERNS WITH RTN

- What Datum is the RTN using?
- What adjustment of the Datum is the RTN using?
- What epoch of the Datum adjustment is the RTN using?
- How Does The RTN Align To The NSRS?
- Can Users Use Any Manufacturers' Equipment In The RTN?
- Do Overlapping Networks Give The Same Coordinates?
- What Are The Field Accuracies?

OVERLAPPING RTN-NSRS?, HOMOGENEOUS?, USES ALL GNSS GEAR?

NATIONAL SPATIAL REFERENCE SYSTEM (NSRS)

Consistent National Coordinate System

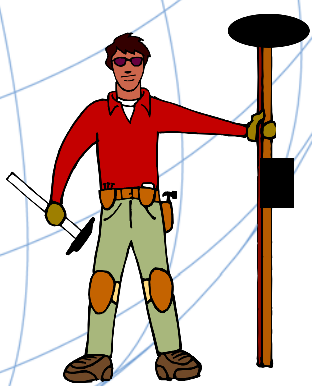
- Latitude
- Longitude
- Height
- Scale
- Gravity
- Orientation

and how these values change with time

HOW WILL NGS HELP THE USER OF RTN?

"Develop guidelines for both the administration and use of real-time GNSS networks and especially for ensuring that these networks are compatible with the NSRS."

1. TOP DOWN: OPUS POSITIONS ON RTN REFERENCE STATIONS AT APPROPRIATE INTERVALS COULD PRODUCE GRAPHICS THAT WOULD SHOW BIASES AT A GLANCE.



2. USER UP: PHYSICAL MONUMENTATION, ESTABLISHED WITH BEST TECHNOLOGY, COULD BE USED AS FIDUCIAL STATIONS TO HELP THE USER VERIFY THAT RTN ARE PRODUCING ACCURATE COORDINATES,

(NEAR) REAL TIME GNSS POSITIONING – BEYOND THE BLACK BOX

HOW DOES RT WORK?

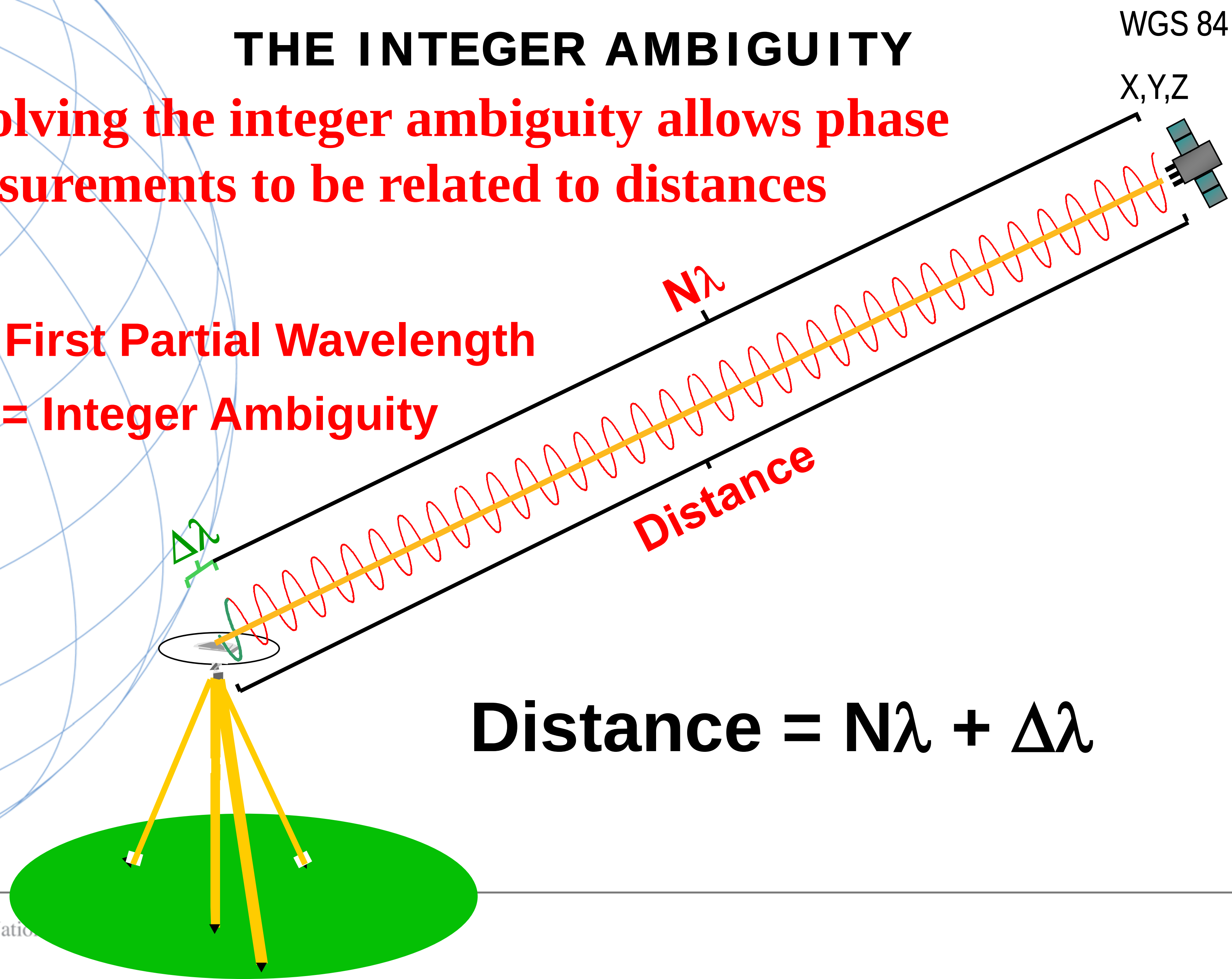
- Δ X,Y,Z FROM BASE (REMEMBER "GIGO")
- MULTILATERATION - TIME (SEC.) · ***C*** *(SPEED OF LIGHT)* (M/SEC.)= *DISTANCE from satellite*
- MUST RESOLVE CARRIER CYCLE INTEGER COUNT AMBIGUITIES (# cycles · wave length + partial cycle = distance)
- MUST ACCOUNT FOR FACTORS AFFECTING THE PATH OF THE SIGNAL
- DUAL FREQUENCY ENABLES "ON THE FLY" RESOLUTION OF THE AMBIGUITIES & EASIER CYCLE SLIP DETECTION THAN L1 ONLY
- FREQUENCY COMBINATIONS AND DIFFERENCING CONTRIBUTE TO MITIGATING THE ERROR BUDGET

THE INTEGER AMBIGUITY

Resolving the integer ambiguity allows phase measurements to be related to distances

Δλ = First Partial Wavelength

Nλ = Integer Ambiguity



Distance = Nλ + Δλ

THE AMBIGUITY SEARCH....

The ambiguity is an *integer* number (a multiple of the carrier wavelength).

The integer is different for the L1 and L2 phase observations.

The integer ambiguity is different for each *satellite-receiver pair.*

The integer ambiguity is a constant for a particular satellite-receiver pair for all epochs of *continuous* tracking (that is, as long as no **cycle slips** occur)

The carrier phase measurement from one observation epoch to another is a measure of the *change* in satellite-receiver range.

The determination of the cycle ambiguity integer is known as **ambiguity resolution**, and is generally not an easy task because of the presence of other biases and errors in the carrier phase measurement.

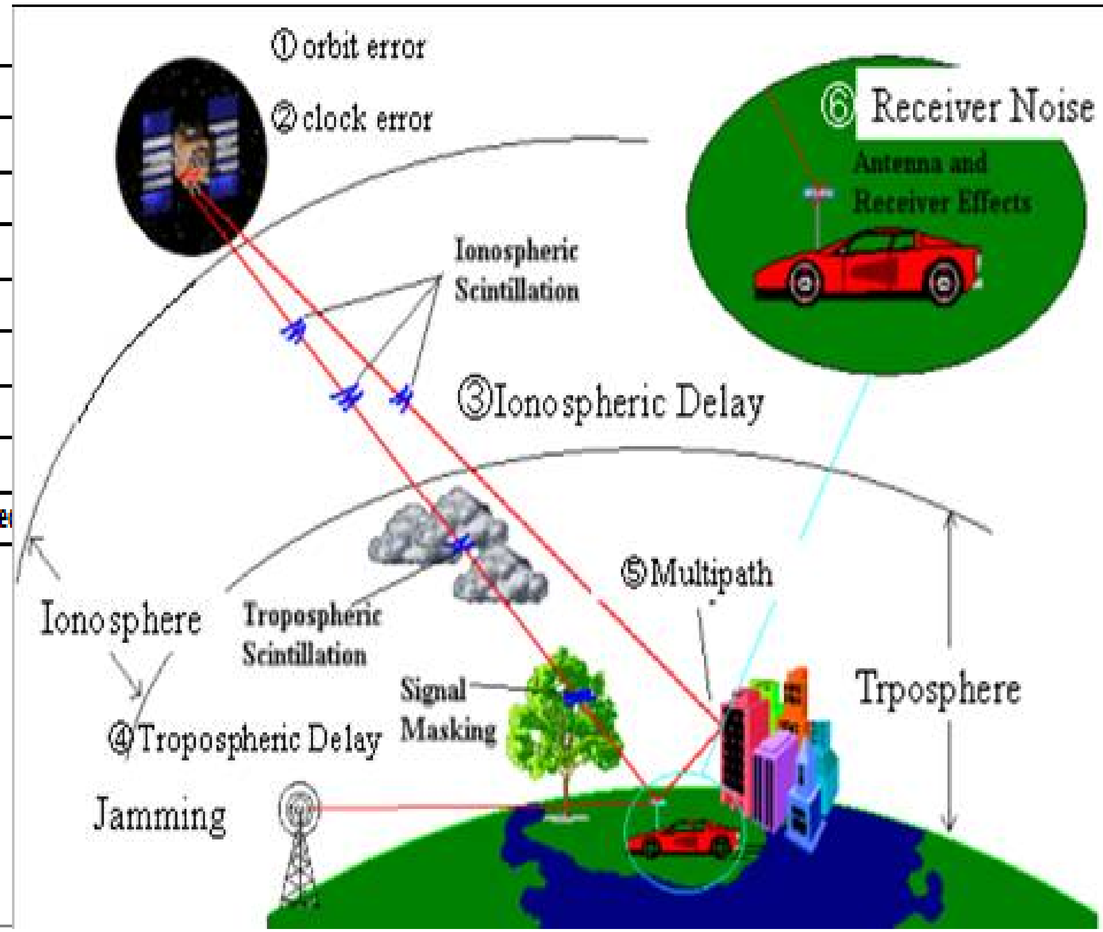

National Geodet
8400 MPH
SVN 31
SVN 14
8400 MPH
SVN 8
SVN 2
8400
8400 MPH
Peter H. Dana 9/22/98
GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination
ERY EPOCH OF
SERVATION
ST COMPUTE
ANGE IN
SITION DUE TO
RTH ROTATION,
TELLITE ORBIT
ANGE AND
LATIVITY!
AT "C", 1 NANOSECOND = 30 CM!
Satellite Generated Carrier
(Doppler Shifted)
Receiver Genera
The Combined B
Signal
Figure 1.10. The Carrier Beat Phase.
Ambiguity searching space
Validation and Rejection Criteria
Searching (Identification) process
no
yes
Assurance Criteria
AMBIGUITY FIXING
eral strategy of on-the-fly ambiguity resolution.

RT PROCESSING IN YOUR ROVER

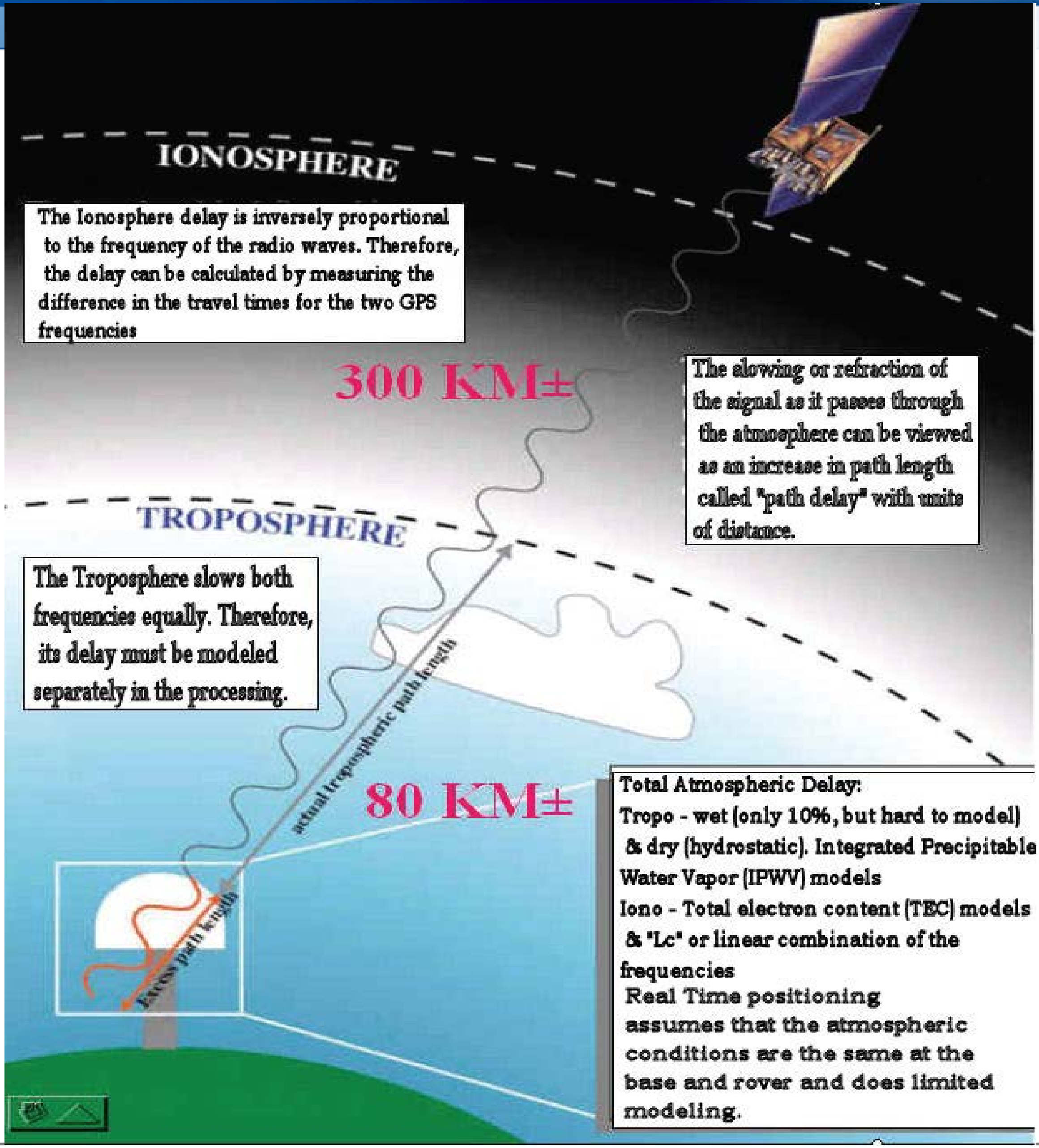
UNDIFFERENCED PHASE OBSERVABLE (CYCLES)

$$\varphi_k^p(t) = \frac{f}{c}\rho_k^p(t) - f\,dt_k(t) + f\,dt^p(t) + N_k^p - I_{k,\varphi}^p(t) + \frac{f}{c}T_k^p(t) + d_{k,\varphi}(t) + d_{k,\varphi}^p(t) + d_\varphi^p(t) + \varepsilon_\varphi$$

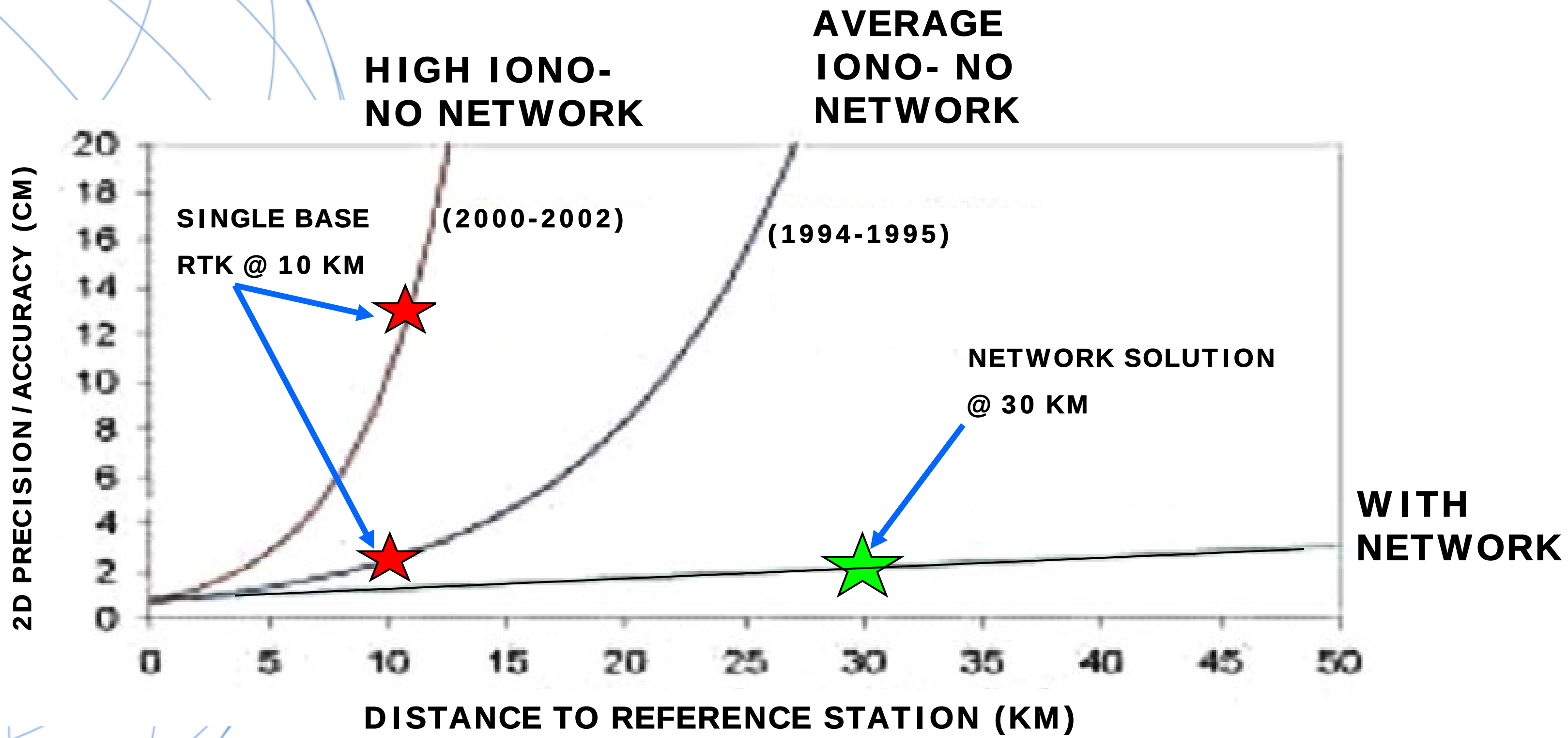
ERROR	VALUE
Ionosphere	4.0 METERS
Ephemeris	2.1 METERS
Clock	2.1 METERS
Troposphere	0.7 METERS
Receiver	0.5 METERS
Multipath	1.0 METERS
TOTAL	10.4 METERS
UNCORRELATEDERROR	5.15 m (square root of sum of errors square



IONO & TROPO LAYERS AND THEIR EFFECT ON THE GNSS SIGNAL



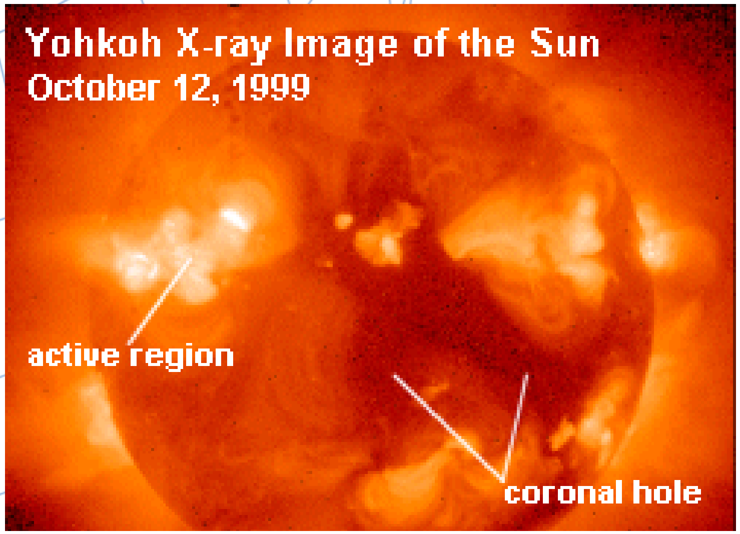
IONOSPHERIC EFFECTS ON POSITIONING

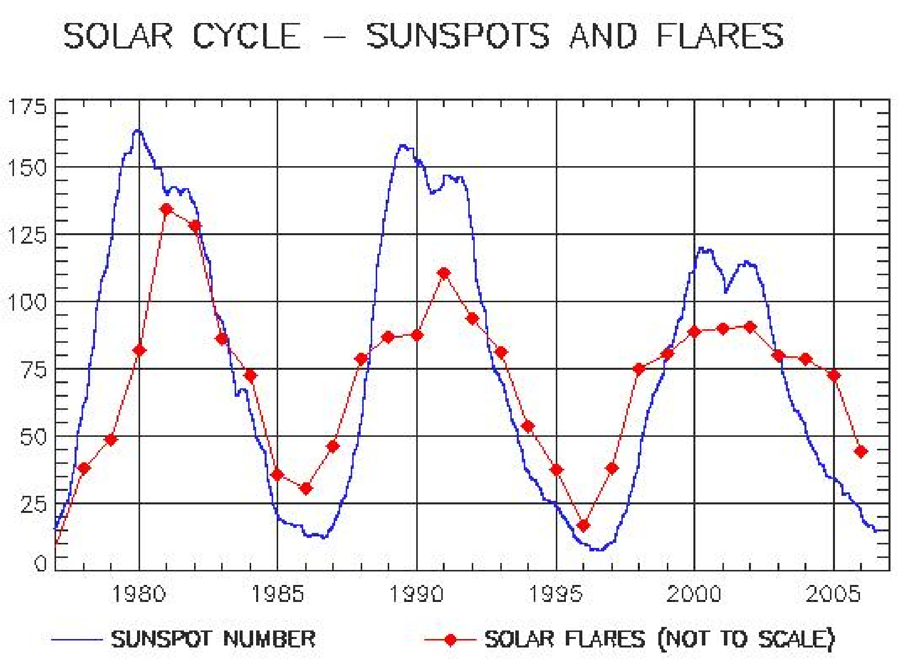


(SOURCE-BKG- GERMANY)

SUNSPOT CYCLE

- Sunspots follow a regular 11 year cycle
- We are just past the low point of the current cycle
- Sunspots increase the radiation hitting the earth's upper atmosphere and produce an active and unstable ionosphere





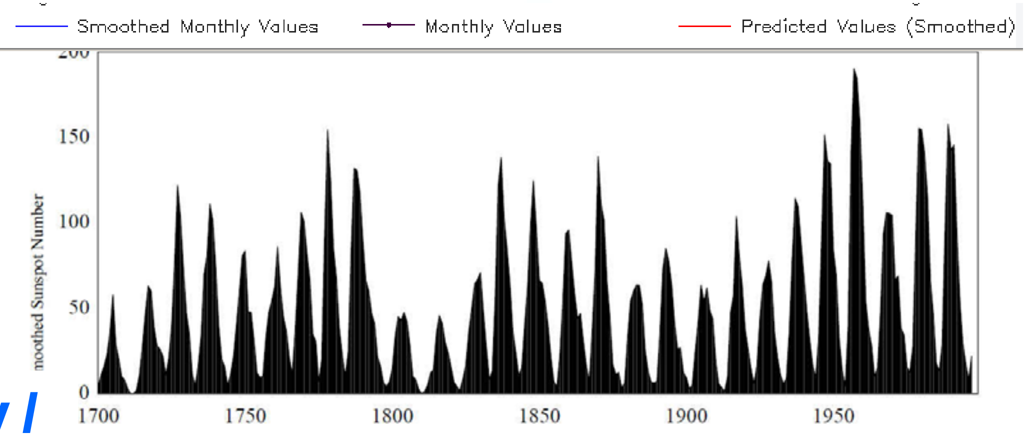


Figure 1. The Sunspot Cycle, well documented over the last 300 years, reveals a 10-11 year pattern of solar activity.

http://www.swpc.noaa.gov/

Official Space Weather Advisory issued by NOAA Space Weather Prediction Center Boulder, Colorado, USA SPACE WEATHER ADVISORY BULLETIN #10- 1 2010 April 05 at 12:13 p.m. MST (2010 April 05 1213 UTC) **** STRONG GEOMAGNETIC

:Product: Geophysical Alert Message wwv.txt
:I
#
#
#
#
So
So
Th

SINGLE FREQUENCY USERS USE A MODEL FOR IONO CORRECTIONS, SO DURING GEOMAGNETIC STORMS, THEY WILL EXPERIENCEMORE DRAMATIC ERROR AND NOISE THAN DUAL+ FREQUENCY USERS WHO MAY USE THE DISPERSIVE CHARACTER OF THE IONOSPHERE TO CALCULATE THE ACTUAL ERROR.

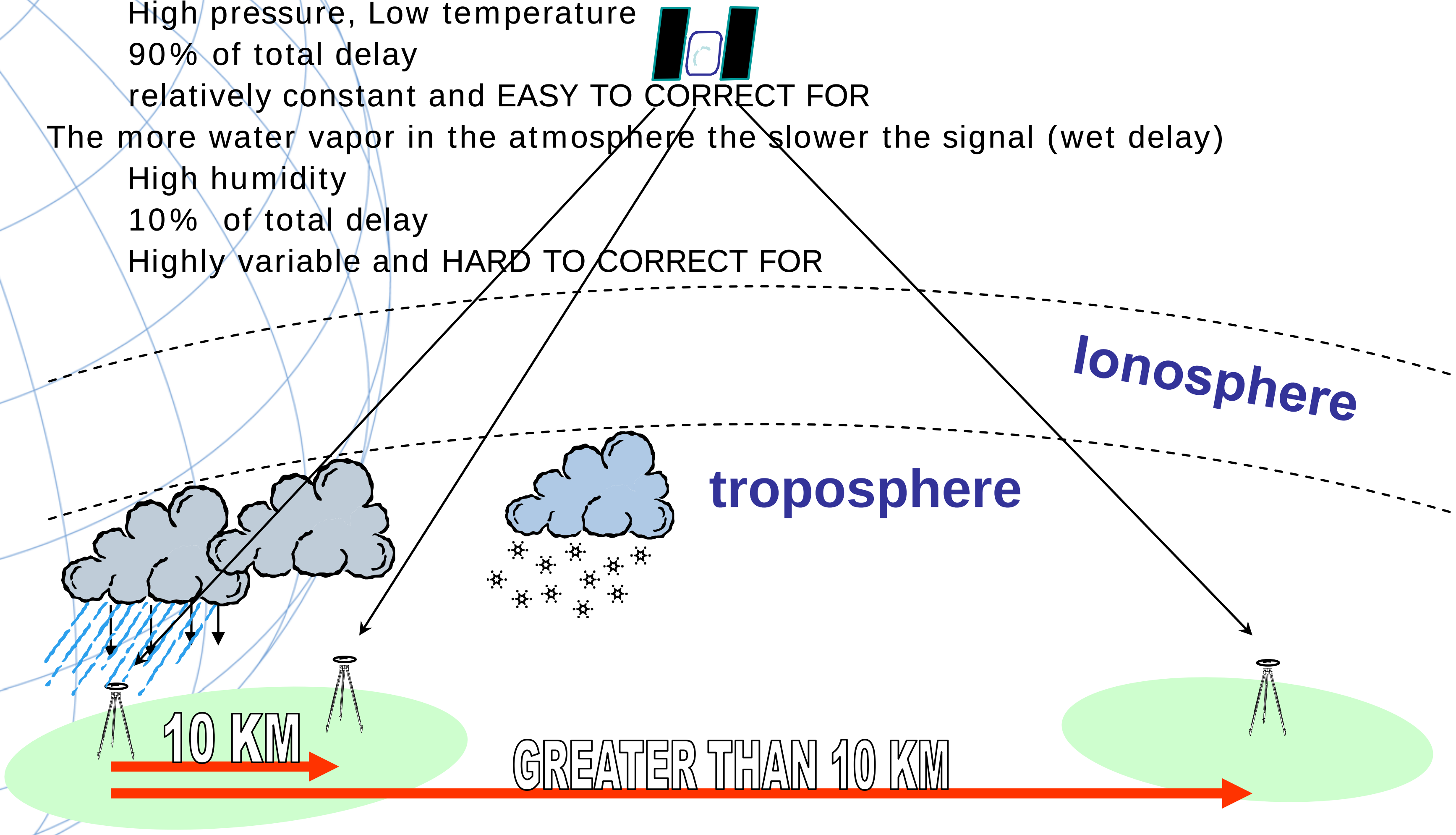
Space weather for the past 24 hours has been strong.
Geomagnetic storms reaching the G3 level occurred.

Space weather for the next 24 hours is expected to be minor.
Geomagnetic storms reaching the G1 level are expected.

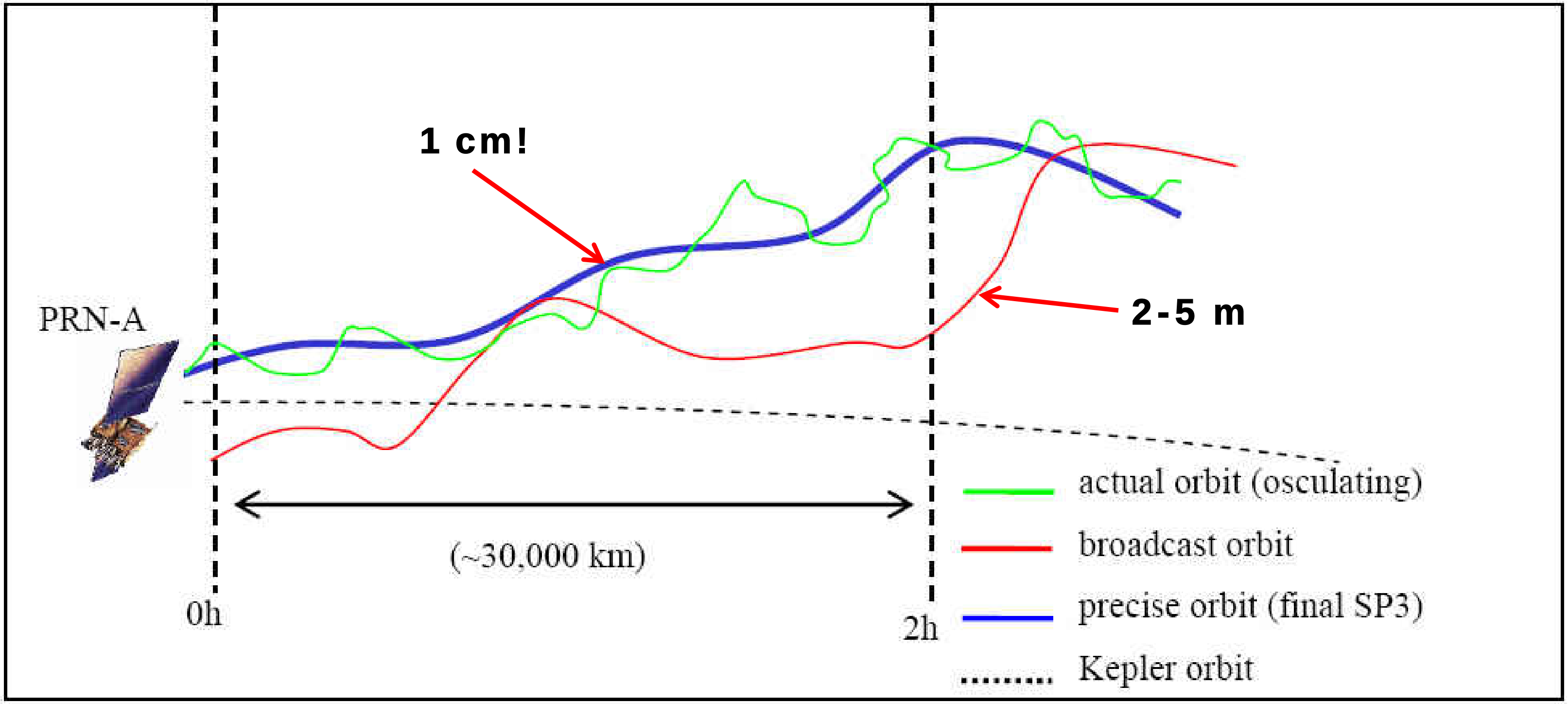
TROPOSPHERE DELAY

The more air molecules, the slower the signal (dry delay)
- High pressure, Low temperature
- 90% of total delay
- relatively constant and EASY TO CORRECT FOR

The more water vapor in the atmosphere the slower the signal (wet delay)
- High humidity
- 10% of total delay
- Highly variable and HARD TO CORRECT FOR



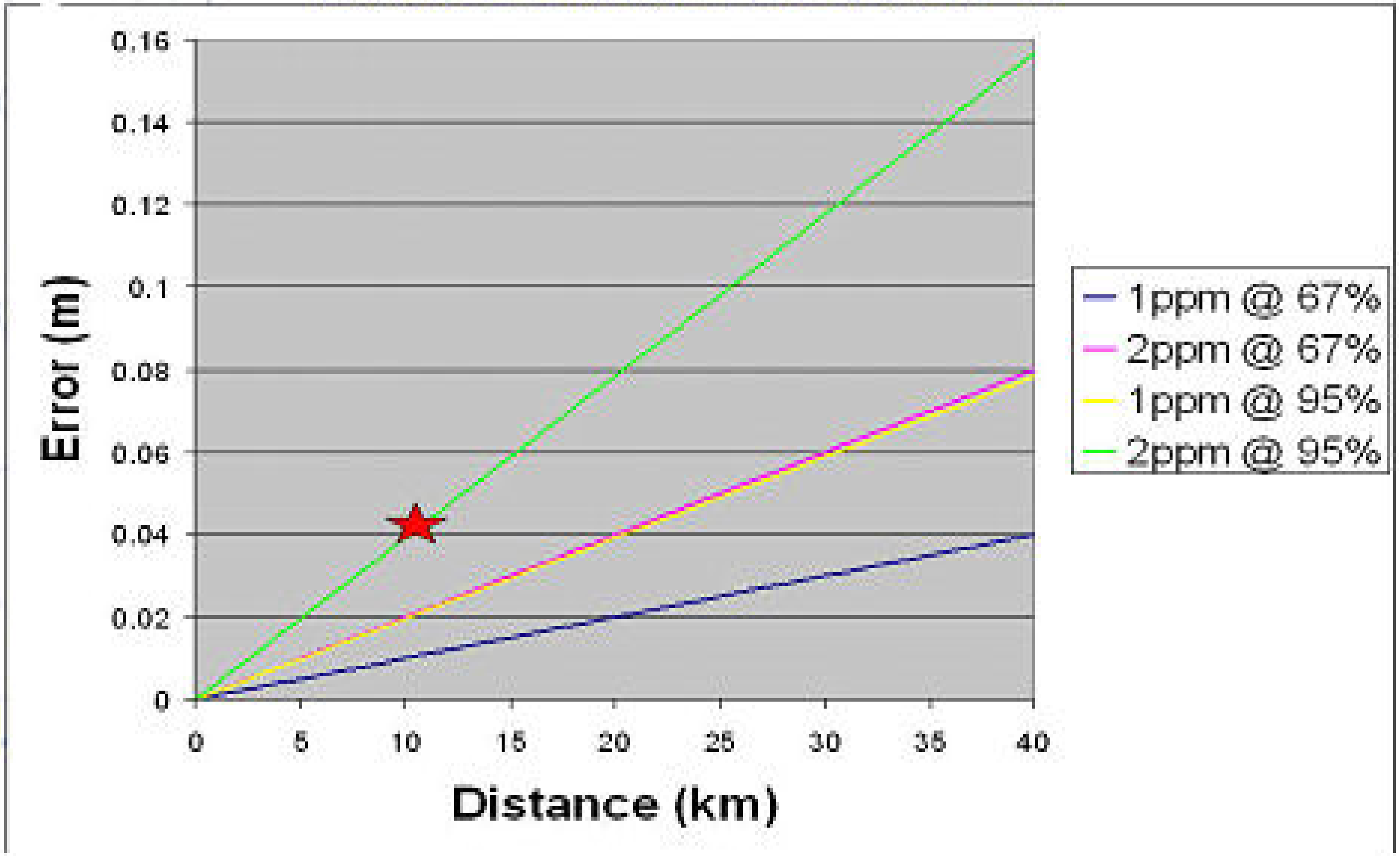
ORBITAL ERRORS CONTRIBUTING TO PPM ERRORS



(See user guidelines references for Graphic: Ahn, 2005)

IONO, TROPO, ORBIT CONTRIBUTE TO PPM ERROR

RTK PPM ERROR VS. BASELINE LENGTH



REMEMBER GNSS EQUIPMENT MANUFACTURERS' SPECS!

THE UNDIFFERENCE CARRIER PHASE OBSERVABLE IN CYCLES

$$\varphi_k^p(t) = \frac{f}{c}\rho_k^p(t) - f dt_k(t) + f dt^p(t) + N_k^p - I_{k,\varphi}^p(t) + \frac{f}{c}T_k^p(t) + d_{k,\varphi}(t) + d_{k,\varphi}^p(t) + d_\varphi^p(t) + \varepsilon_\varphi$$

Superscripts refer to the satellite, subscripts refer to ground station

φ : Carrier phase observable in cycles φ_k^p refers to the carrier phase observable from SV p to Station k.

f : Carrier frequency

c : Speed of light

$\rho(t)$: The topocentric range ρ_k^p is the range from SV p to Station k.

$dt_k(t)$: Receiver clock error as a function of time

$dt^p(t)$: SV clock error as a function of time

N_k^p : The integer ambiguity from SV p to Station k

$I_k^p(t)$: Ionospheric advance $I_{k,\varphi}^p$ is the Ionospheric advance from SV p to Station k in cycles

$T(t)$: Tropospheric delay T_k^p is the tropospheric delay from SV p to Station k

$d_{k,\varphi}(t)$: Receiver hardware delays in cycles as a function of time

$d_{k,\varphi}^p(t)$: Multipath in cycles as a function of time

$d_\varphi^p(t)$: Satellite hardware delays in cycles as a function of time

ε_φ : Measurement noise in cycles

THE CYCLE COUNT COOKBOOK-
USING DIFFERENCING TO ELIMINATE OR REDUCE COMMON ERRORS IN THE RECEIVER AND SATELLITE

$$\varphi_k^p(t) = \frac{f}{c}\rho_k^p(t) - f dt_k(t) + f dt^p(t) + N_k^p - I_{k,\varphi}^p(t) + \frac{f}{c}T_k^p(t) + d_{k,\varphi}(t) + d_{k,\varphi}^p(t) + d_\varphi^p(t) + \varepsilon_\varphi$$

- RECEIVER HARDWARE DELAYS
- SATELLITE HARDWARE DELAYS
- RECEIVER CLOCK BIAS
- SATELLITE CLOCK BIAS

→ ELIMINATED WITH DIFFERENCING

- IONO DELAY
- TROPO DELAY

→ SAME AS BASE WITH SINGLE BASE INTERPOLATED WITH RTN

- MEASUREMENT NOISE (HIGHER GRADE RECEIVERS = LESS NOISE)
- MULTIPATH

→ NOT ELIMINATED WITH DIFFERENCING

RESULTING DIFFERENCED PHASE OBSERVABLE (CYCLES)

$$\varphi_k^p(t) = \frac{f}{c}\rho_k^p(t) - f\,dt_k(t) + f\,dt^p(t) + N^p - I_{k,\varphi}^p(t) + \frac{f}{c}T_k^p(t) + d_{k,\varphi}(t) + d_{k,\varphi}^p(t) + d_\varphi^p(t) + \varepsilon_\varphi$$

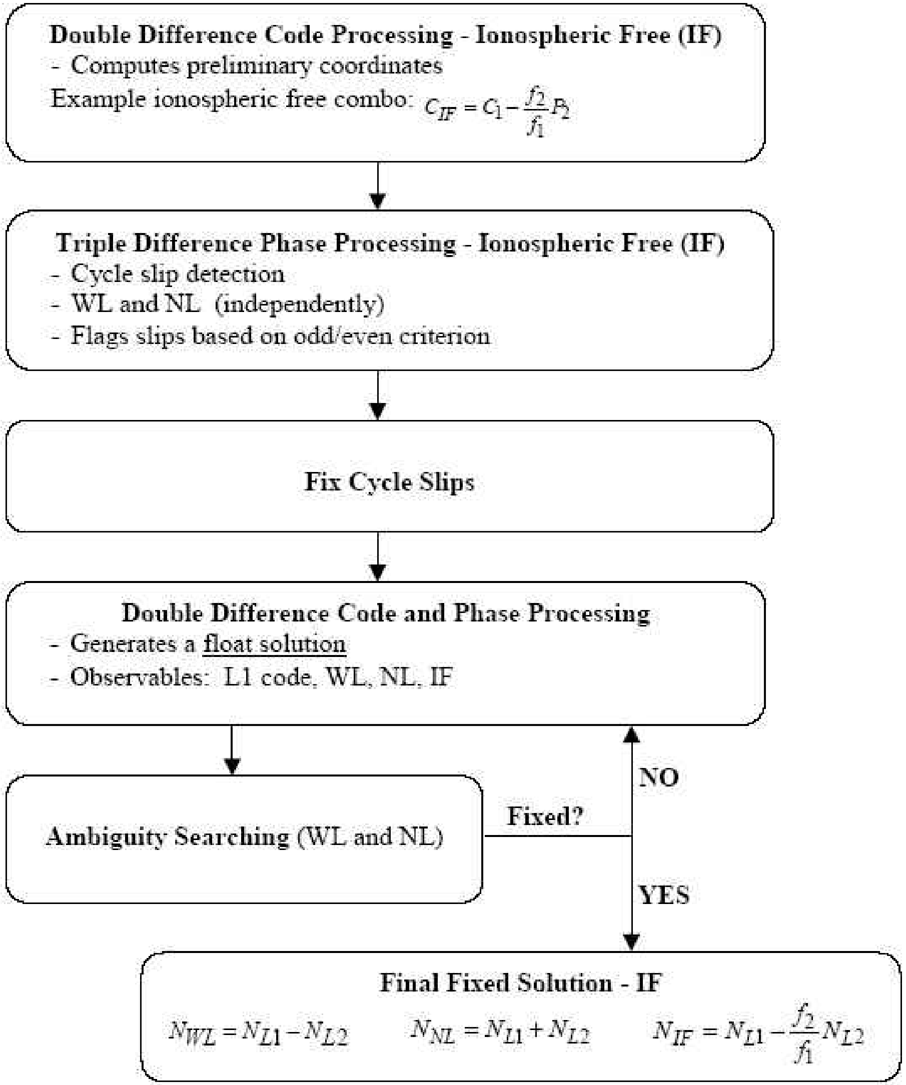
Superscripts refer to the satellite, subscripts refer to ground station

LEAVES MULTIPATH, MEASUREMENT NOISE & RANGE TO SATELLITE

ASSUMED THE SAME FOR ROVER & BASE

OR MODELED BY RTN

CARRIER PHASE PROCESSING FLOW



REFERENCE:

“Parameterization of DGPS Carrier Phase Errors Over a Regional Network of Reference Stations”
(URL: http://www.geomatics.ucalgary.ca/GradTheses.html)
by
Georgia Fotopoulos
August 2000

BEST METHODS FOR REAL TIME POSITIONING

REAL-TIME CHOICES - BIG PICTURE ISSUES

- PASSIVE / ACTIVE – WHAT IS 'TRUTH'?
- GEOID + ELLIPSOID / LOCALIZE –
  QUALITY OF GEOID MODELS LOCALLY.
  ORTHOMETRIC HEIGHTS ON CORS?
- GRID / GROUND –
  LOW DISTORTION PROJECTIONS- SHOULD NGS PLAY?
- ACCURACY / PRECISION- IMPORTANCE OF METADATA
- SINGLE SHOT / REDUNDANCY
- RTK / RTN
- NATIONAL DATUMS / LOCAL DATUMS / ADJUSTMENTS-
  DIFFERENT WAYS RTN GET THEIR COORDINATES- VARIOUS OPUS, OPUS-DB, CORS ADJUSTED, PASSIVE MARKS.
  VELOCITIES - NEW DATUMS, "4 -D" POSITIONS
- GNSS / GPS

FOUR CARDINAL RULES FOR RT POSITIONING

- COMMUNICATIONS: THE KEY TO SUCCESS
- CHECK SHOT: FIRST BEFORE NEW WORK
- REDUNDANCY: FOR CONFIDENCE
- MULTIPATH: AVOID UNSUITABLE CONDITIONS

NGS SINGLE BASE GUIDELINES

- LEGACY EQUIPMENT
- NO CELL COVERAGE
- NEW RT CLOSEST BASE NETWORKS
- MACHINE GUIDANCE AND PRECISION AGRICULTURE USE

National Geodetic Survey Positioning America for the Future www.ngs.noaa.gov

User Guidelines for Single Base Real Time GNSS Positioning

William Henning, Lead Author

National Oceanic and Atmospheric Administration • National Geodetic Survey

http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v2.1.pdf

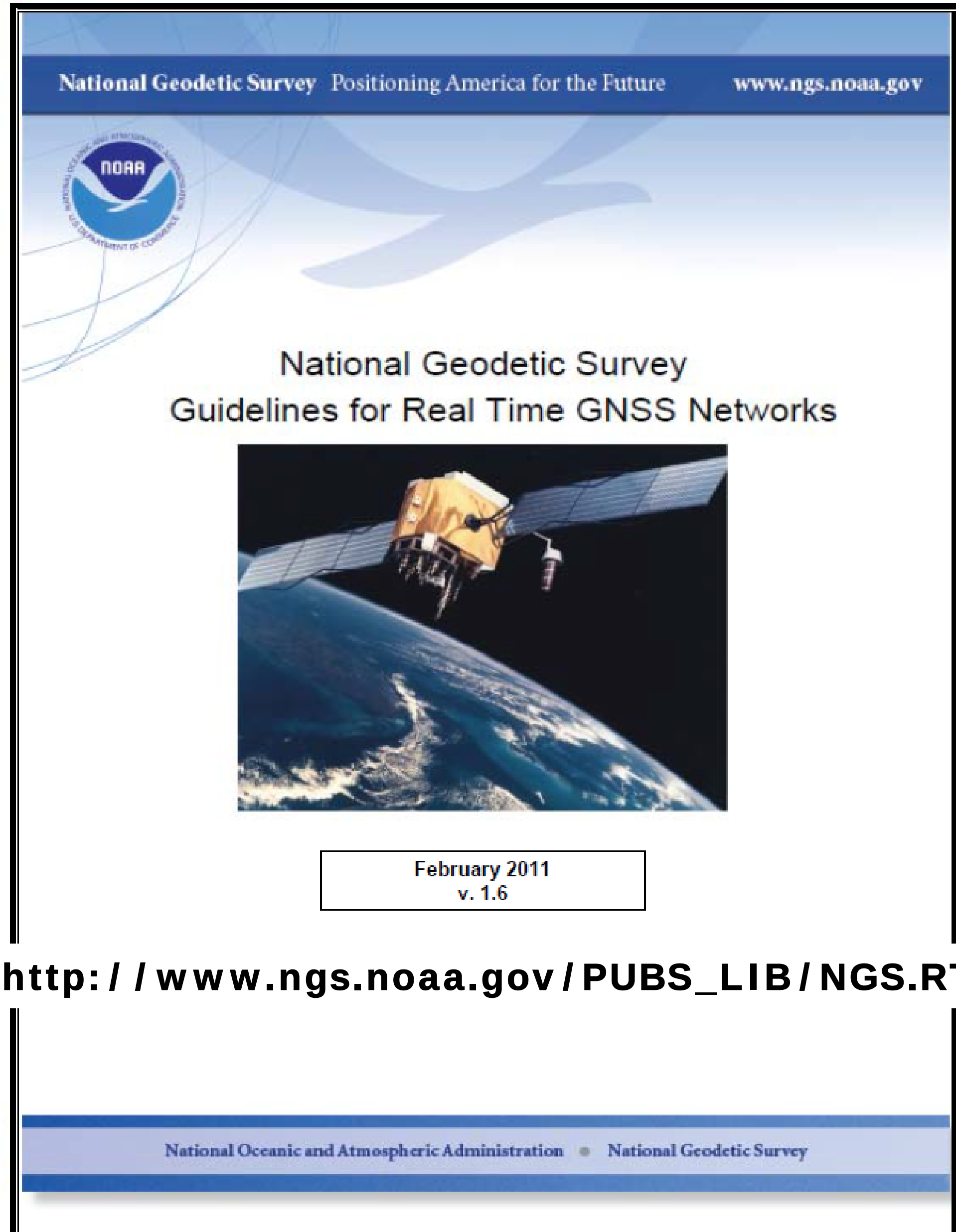
Table of Contents

RT USER GUIDELINES

DRAFT GUIDELINES- 95% CONFIDENCE

ACCURACY CLASS SUMMARY TABLE

	CLASS RT1	CLASS RT2	CLASS RT3	CLASS RT4
ACCURACY (TO BASE)	0.015 HORIZONTAL., 0.025 VERTICAL	0.025 HORIZONTAL., 0.04 VERTICAL	0.05 HORIZONTAL., 0.06 VERTICAL	0.15 HORIZONTAL., 0.25 VERTICAL
REDUNDANCY	≥ 2 LOCATIONS, 4-HOUR DIFFERENTIAL	≥ 2 LOCATIONS, 4-HOUR DIFFERENTIAL	NONE	NONE
BASE STATIONS	≥ 2 , IN CALIBRATION PROJECT CONTROL	RECOMMEND 2 IN CALIBRATION	≥ 1 , IN CALIBRATION	≥ 1 , IN CALIBRATION RECOMMENDED
PDOP	≤ 2.0	≤ 3.0	≤ 4.0	≤ 6.0
RMS	≤ 0.01 M	≤ 0.015 M	≤ 0.03 M	≤ 0.05 M
COLLECTION INTERVAL	1 SECOND FOR 3-MINUTES	5 SECONDS FOR 1-MINUTE	1 SECOND FOR 15 SECONDS	1 SECOND FOR 10 SECONDS
SATELLITES	≥ 7	≥ 6	≥5	≥ 5
BASELINE DISTANCE	≤ 10 KM	≤ 15 KM	≤ 20 KM	ANY WITH FIXED SOLUTION
TYPICAL APPLICATIONS	PROJECT CONTROL CONSTRUCTION CONTROL POINTS CHECK ON TRAVERSE, LEVELS SCIENTIFIC STUDIES PAVING STAKE OUT	DENSIFICATION CONTROL TOPOGRAPHIC CONTROL PHOTOPOINTS UTILITY STAKE OUT	TOPOGRAPHY CROSS SECTIONS AGRICULTURE ROAD GRADING SITE GRADING	SITE GRADING WETLANDS GIS POPULATION MAPPING ENVIRONMENTAL



http://www.ngs.noaa.gov/PUBS_LIB/NGS.RTN.Public.v2.0.pdf

RTN GUIDELINES FOR GNSS POSITIONING–

WILL NOT SPECIFY OR DEFINE A STANDARD, BUT WILL HELP ADMINISTRATORS AND USERS TO BE AWARE OF ALL THE ISSUES INVOLVED WITH THIS NEW TECHNOLOGY

60+ CONTRIBUTORS:

- NGS ADVISORS
- DOT
- STATE GEODETIC SURVEYS
- GNSS MANUFACTURERS
- SRCs
- BLM, NPS

VI. RTN User Guidelines

A. Benefits to the user of an RTN over single-base Real Time (R include:

1. No user base station is necessary. Therefore, there are with the base, no control recovery is necessary to establis and the user needs only half the equipment to produce R conversely, one can double productivity). Additionally, t time setting up and breaking down the base station equip
2. The first order ppm (part per million) error is eliminate reduced) because ionospheric, tropospheric and orbital er interpolated to the site of the rover. This enables centime positioning at extended ranges over 10 km from a referen
3. The network can be aligned with the NSRS with high users will then be collecting positional data that will fit to seamlessly across the RTN coverage. This is important to geospatial data, such as GIS professionals who by using may deal with such regional issues as emergency manage security issues.
4. Datum readjustments or changes can be done transpare with no post campaign work. New datum adjustments to transformations to another geodetic datum such as the Int Terrestrial Reference Frame (ITRF) or the forthcoming r NAD 83 (NGS, 2008) are done at the network level and the users.
5. With some business models, the user can share in the r installing a network reference station and getting a share subscription fees imposed upon other network users.
6. Different formats and accuracies are readily available. environmental resource data, mapping grade data, etc. ca with 30 to 60 centimeter accuracy while surveyors and er access the network with one centimeter level accuracy. R and other binary formats can be user selected.
7. The RTN can be quality checked and monitored in rel using utilities such as OPUS from NGS (http://www.ngs. and TEQC from UNAVCO (http://facility.unavco.org/software/teqc/teqc.html) .

B. Drawbacks to the user of an RTN compared to classical RT p include:

1. Network subscription fees. These may be prohibitive f companies – even though there are considerable savings equipment .

F. Best Methods for RTN Users – The "Seven C's" of NOAA's NGS

This section in conjunction with the information and recommendations contained in the existing NGS guidelines for RT single base positioning (Henning, 2008), is given as a means to produce accurate, repeatable, homogenous positions at the 95% confidence level. It is understood that other methodology may produce similar results; however, these guidelines are given as a confident path that will lead to the stated precision and accuracy.

1. Check Equipment, Data Collector Parameters & Site information

a) Measure the actual height of the antenna reference point (ARP) on the rover pole at the start of a campaign.
b) Ensure that all necessary and correct projection parameters are in the data collector.
c) Ensure that all project data are in the data collector. It is critical that the correct project calibration (a.k.a.localization), if any, is being used. Project control coordinates must be current.
d) Adjust the rover pole bubble before every campaign.
(see http://www.surveying.com/tech_tips/details.asp?techTipNo=19 "Adjustment of the Circular Vial") (SECO, 2009a)
(see http://www.surveying.com/tech_tips/details.asp?techTipNo=13 for pole bubble calibration). (SECO, 2009b)
e) Test wireless data communications (cell/CDMA/SIM card/etc.) for Internet connectivity at the project site.
f) Make sure the GNSS unit and the communication device batteries are fully charged and that there are backups.
g) For orthometric heights, be sure to preload the current geoid model supplied by the NGS. To obtain a reasonably sized file for upload, a regional section of the national model can be extracted in all major GNSS manufacturers' software packages.

2. Conditions

a) Use mission planning in the GNSS manufacturer's software to assess approximate times of poor DOP and/or low number of satellites. The Russian GLONASS constellation is on track to have full operational capability by the end of 2010. While there is little improved accuracy at the present time using the GLONASS constellation, it does enable RT positioning where GPS alone would not permit because of an inadequate number of satellites.

"CONFIDENCE" IN YOUR POSITION INCREASES WITH:

- MORE SATELLITES
- SHORTER BASELINES
- LOWER 'DOP'
- MORE OPEN SKY
- LOWER RMS
- CONTINUOUS COMMUNICATION
- REDUNDANCY, REDUNDANCY, REDUNDANCY

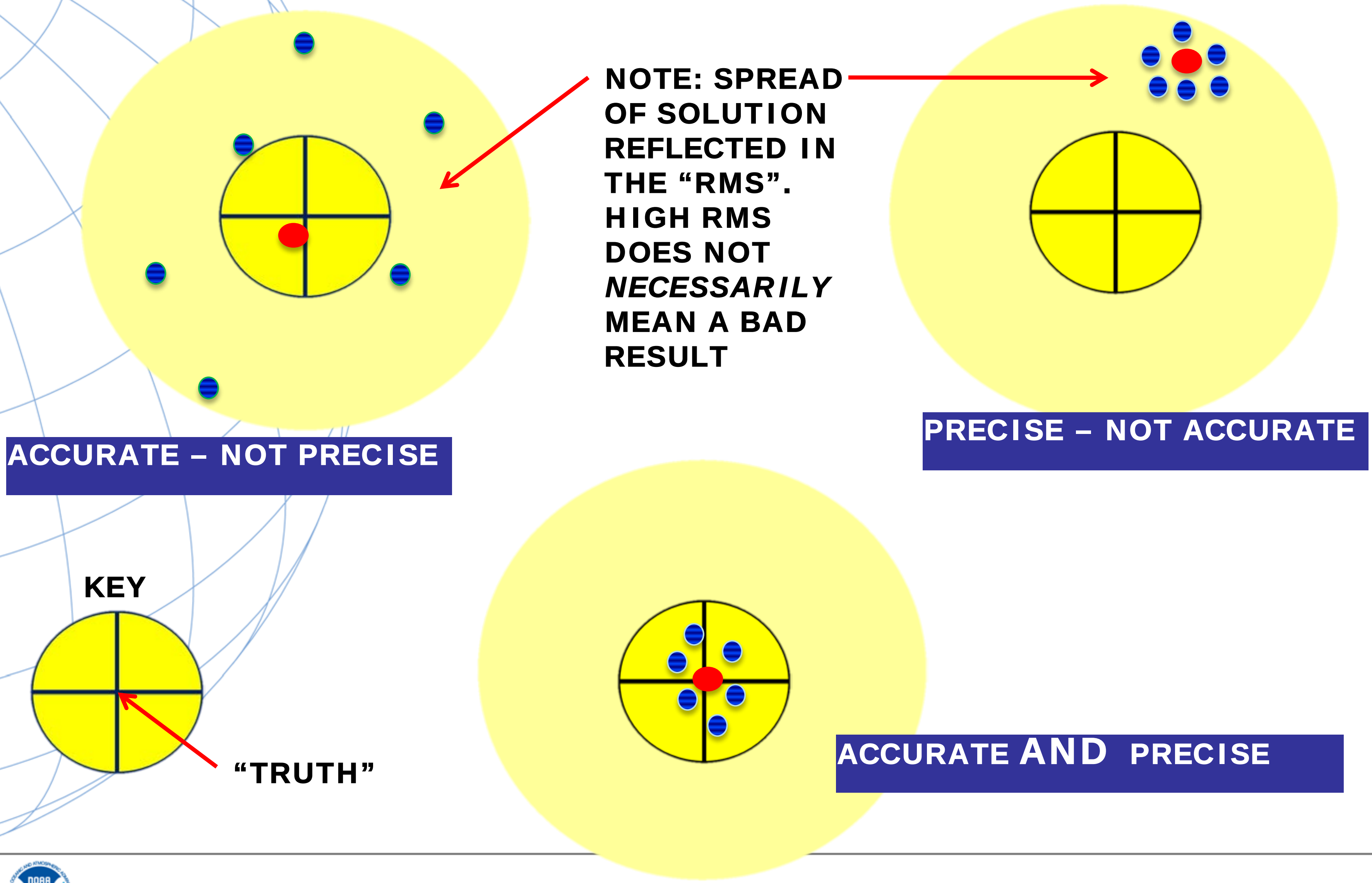
(THE BEST OF ALL SINGLE BASE WORLDS = 8 GPS SATELLITES, GDOP 1.5, 2 KM BASELINE, RMS ≤ 0.01 M, OPEN SKY, NO WEATHER ELEMENTS, SOLID COMMUNICATION)

PRECISION VS. ACCURACY

- "PRECISION" IS A COMPUTED STATISTICAL QUANTITY TO THE *SOURCE* OF THE MEASUREMENT - ALIGNMENT TO THE RTN OR PASSIVE MARK SHOWS PRECISION OF THE OBSERVATION (PER THE DATA COLLECTOR).

- "ACCURACY" IS A COMPUTED STATISTICAL QUANTITY TO THE REALIZATION OF THE DATUM - ALIGNMENT OF THE RTN OR PASSIVE MARK TO THE NSRS SHOWS ACCURACY (PER ESTABLISHED METHODOLGY)
-

PRECISION vs. ACCURACY



BEST METHODS FROM THE GUIDELINES:

THE 7 "C's"

- CHECK EQUIPMENT
- COMMUNICATION
- CONDITIONS
- CONSTRAINTS(OR NOT)
- COORDINATES
- COLLECTION
- CONFIDENCE

THE CONTROL IS AT THE POLE

ACHIEVING ACCURATE, RELIABLE POSITIONS USING GNSS REAL TIME TECHNIQUES

FROM NGS SINGLE BASE GUIDELINES CHAPTER 5 - FIELD PROCEDURES, AND "USERS" CHAPTER OF RTN GUIDELINES:

RT = single base, either active or passive

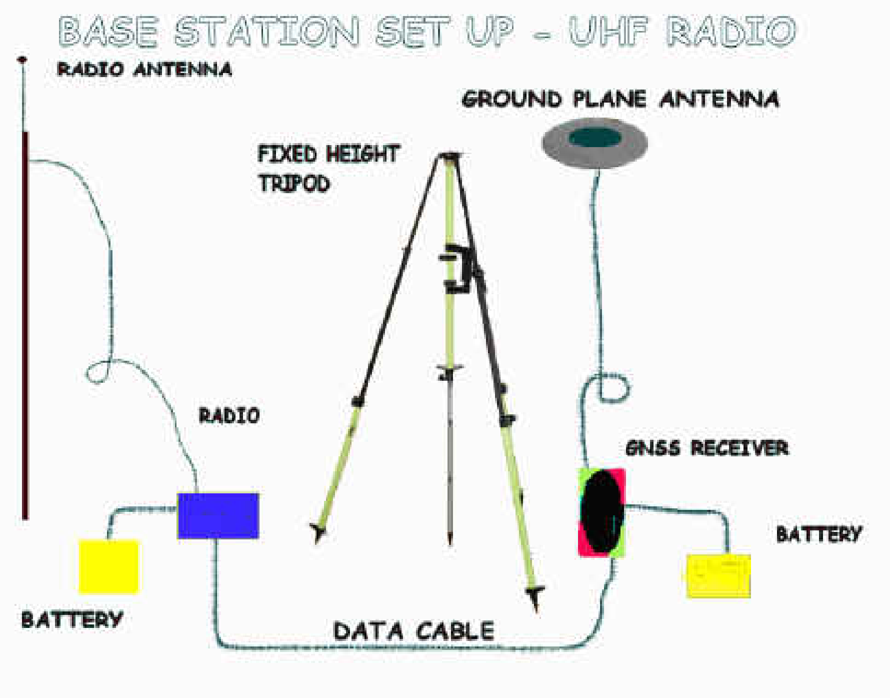
B = Both Single base and RTN

CHECK EQUIPMENT

- B BUBBLE- ADJUSTED?
- RT BATTERY- BASE FULLY CHARGED 12V?
- B BATTERY – ROVER SPARES?
- RT USE PROPER RADIO CABLE (REDUCE SIGNAL LOSS)
- RT RADIO MAST HIGH AS POSSIBLE? (5’ = 5 MILES, 20’ = 11 MILES, DOUBLE HEIGHT=40% RANGE INCREASE). LOW LOSS CABLE FOR >25’.
- RT DIPOLE (DIRECTIONAL) ANTENNA NEEDED?
- RT REPEATER?
- RT CABLE CONNECTIONS SEATED AND TIGHT?
- B“FIXED HEIGHT” CHECKED?
- RT BASE SECURE?

COMMUNICATION

- RT UHF FREQUENCY CLEAR?
- B CDMA/CELL - STATIC IP FOR COMMS?
- B CONSTANT COMMS WHILE LOCATING
- RT BATTERY STRENGTH OK?
- B CELL COVERAGE?
- B KEEP FIRMWARE UPDATED



CONDITIONS

- RT WEATHER CONSISTENT BASE & ROVER?
- B CHECK SPACE WEATHER?
- B CHECK PDOP/SATS FOR THE DAY?
- RT OPEN SKY AT BASE?
- RT MULTIPATH AT BASE?
- B MULTIPATH AT ROVER?
- B USE BIPOD?

Dilution Of Precision - DOP

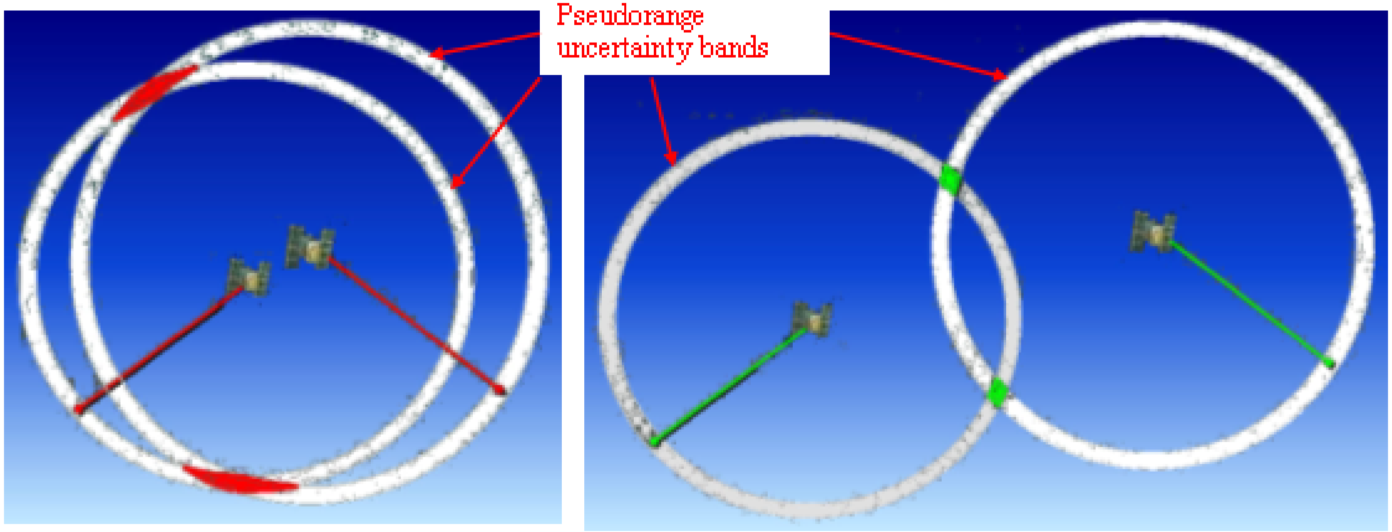


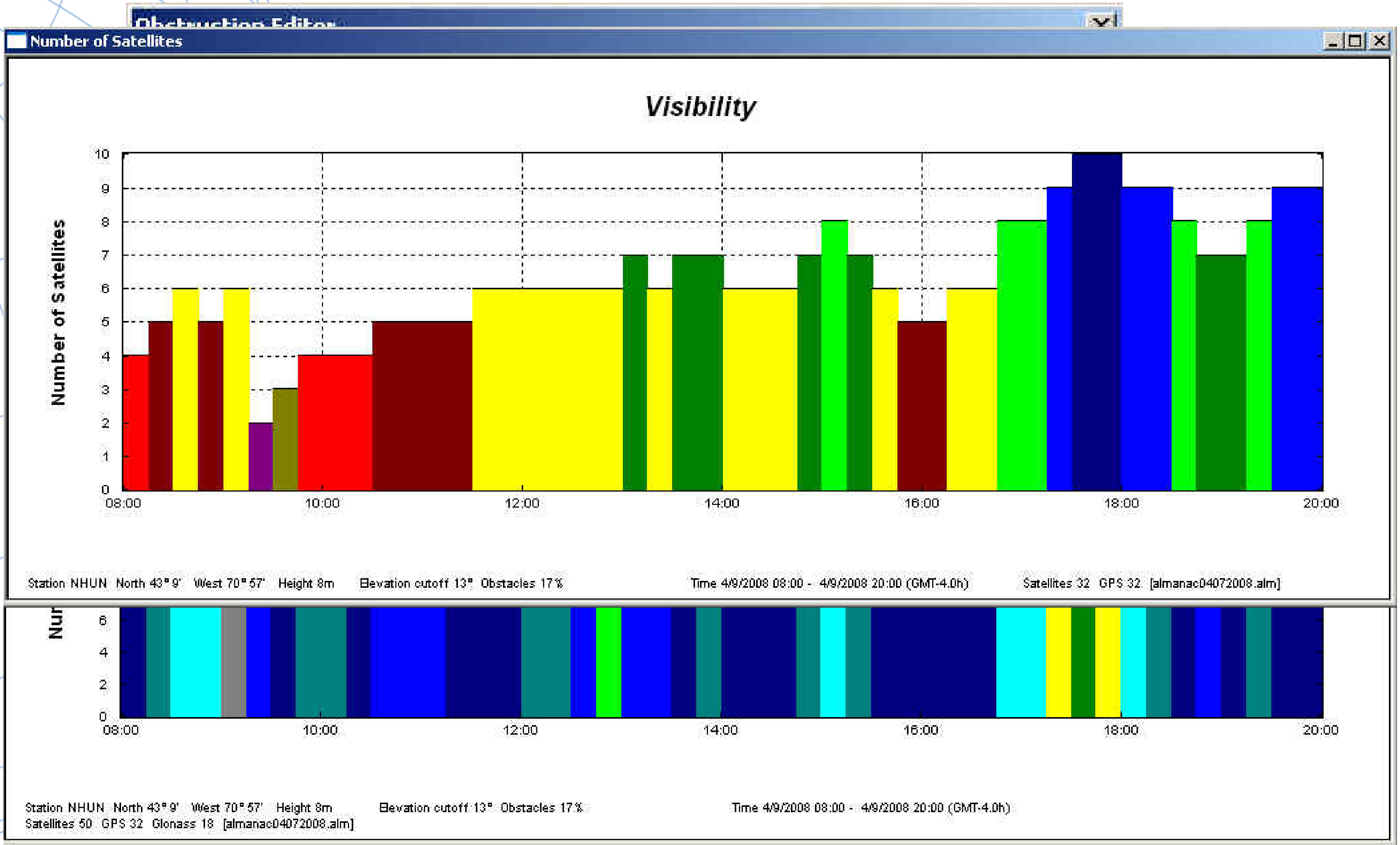
Diagram II-2 Diagram II-3

High PDOP- Satellites Close Together

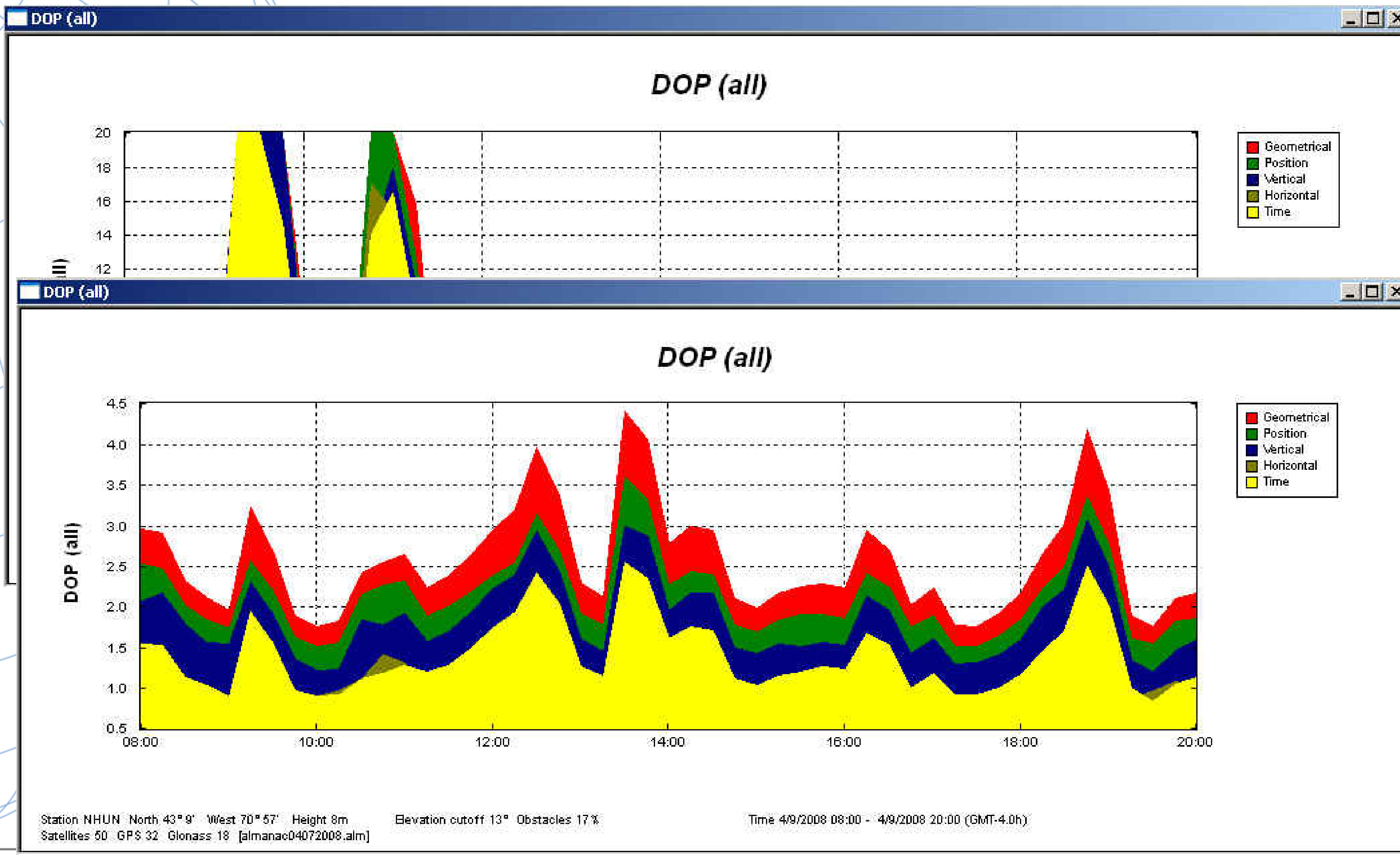
Low PDOP – Satellites Spread.

Note the difference in area of the intersections. In a three Dimensional sense with multiple satellites, it would be reflected in the difference of hyperbolic intersections displayed in polyhedron volumes. Mathematically, the lowest possible volume polyhedron formed by the signal intersections would have the lowest PDOP.

NHUN – SATELLITES/ WITH OBSTRUCTIONS



NHUN – DOP / WITH OBSTRUCTIONS



GPS AND GLN

Table 1 Comparison of GLONASS and GPS Characteristics

Parameter	Detail		GLONASS	GPS
Satellites	Number of satellites		21 + 3 spares [a]	21 + 3 spares [a]
	Number of orbital planes		3	6
	Orbital plane inclination (degrees)		64.8	55
	Orbital radius (kilometers)		25 510	26 560
Signals	Fundamental clock frequency (MHz)		5.0	10.23
	Signal separation technique [b]		FDMA	CDMA
	Carrier frequencies (MHz)	L1	1598.0625 - 1609.3125 [c]	1575.42
		L2	1242.9375 - 1251.6875	1227.6
	Code clock rate (MHz)	C/A	0.511	1.023
		P	5.11	10.23
	Code length (chips)	C/A	511	1 023

DUAL CONSTELLATION RT POSSIBILITIES:

GPS ≥ 5, GLN = 0

GPS = 4, GLN = 2

GPS = 3, GLN = 3

GPS = 2, GLN = 4

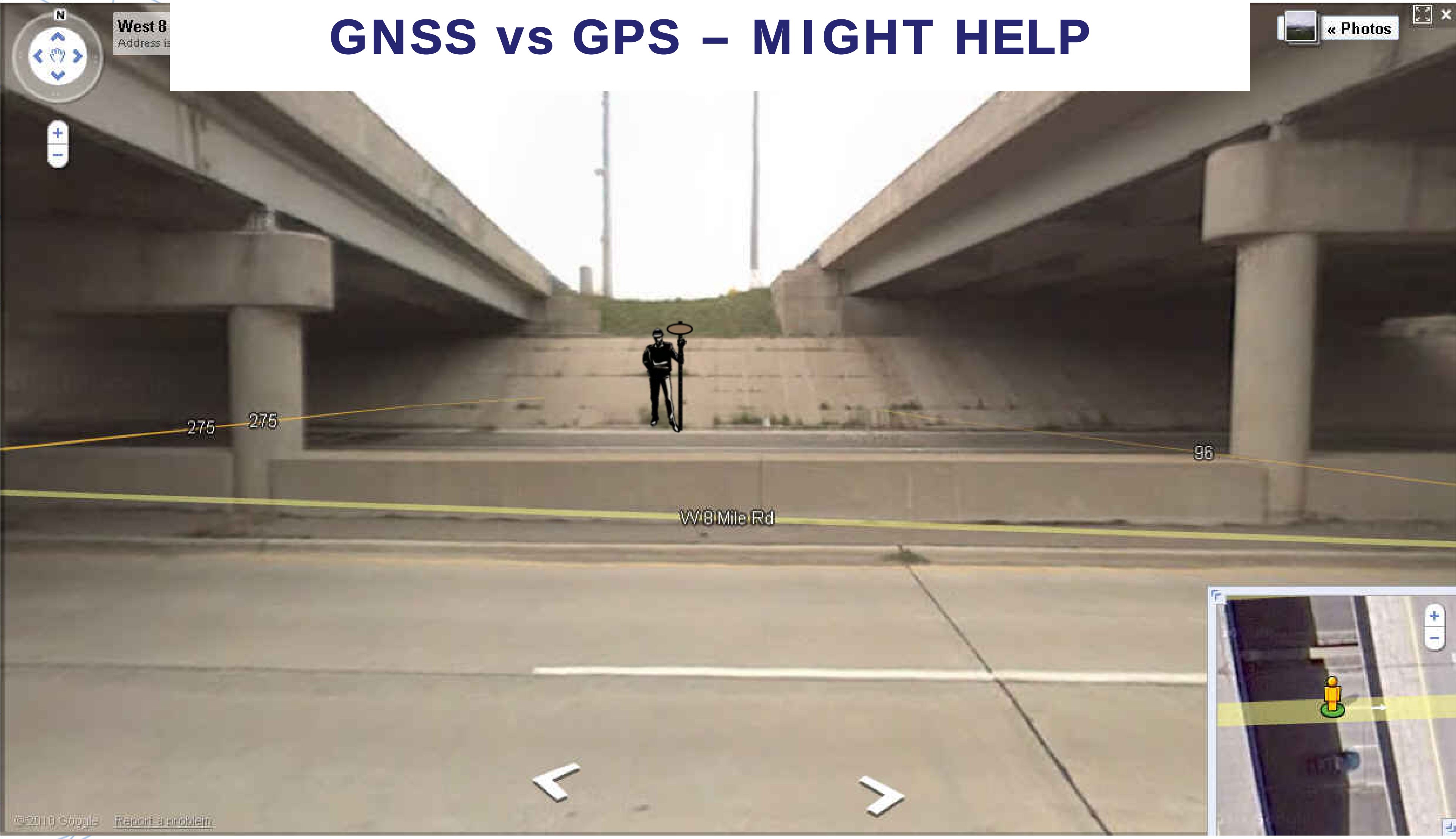
(Can't initialize with only GLN Sats.)

URBAN CANYONS
GNSS vs GPS – MIGHT HELP

HIGHWAY CORRIDORS
GNSS vs GPS – MIGHT HELP

ROUTE OBSTRUCTIONS

GNSS vs GPS – MIGHT HELP



COORDINATES

- B TRUSTED SOURCE?
- B WHAT DATUM/EPOCH ARE NEEDED?
- RT GIGO★
- B ALWAYS CHECK KNOWN POINTS.
- B PRECISION VS. ACCURACY
- B GROUND/PROJECT VS. GRID/GEODETIC
- B GEOID MODEL QUALITY
- B LOG METADATA

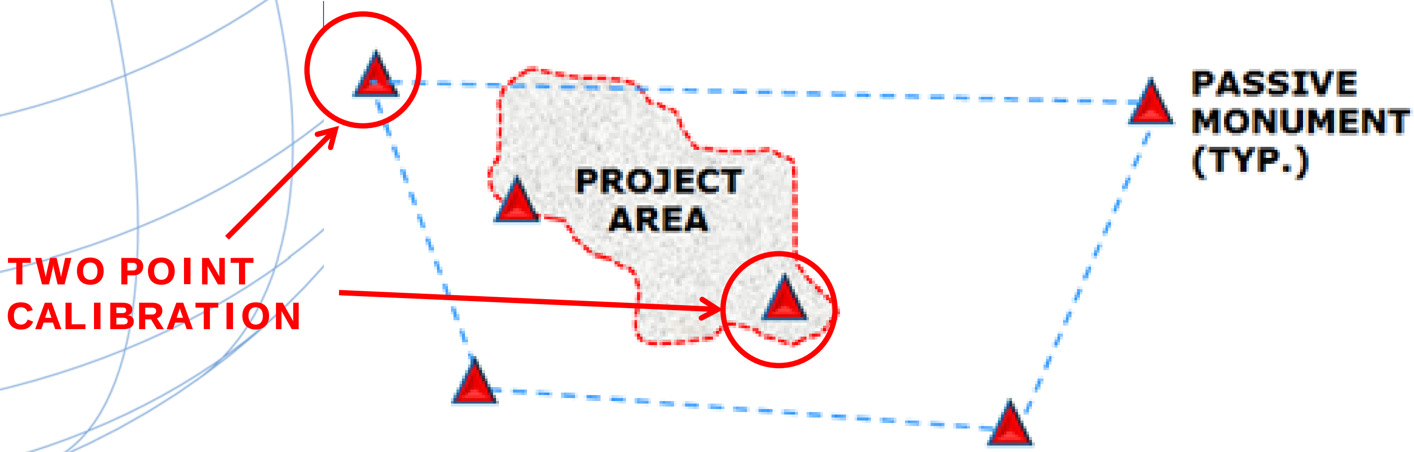
★ AUTONOMOUS LOCAL BASE STATION POSITION ARE OK IF CORRECT COORDINATES ARE INTRODUCED IN THE PROJECT FIRMWARE/SOFTWARE LATER

CONSTRAINTS (OR NOT)

- B ≥ 4 H & V, KNOWN & TRUSTED POINTS?
- B LOCALIZATION RESIDUALS-OUTLIERS?

FYI: GNSS CAN PROVIDE GOOD *RELATIVE* POSITIONS IN A PROJECT WHILE STILL NOT CHECKING TO KNOWNS IN AN ABSOLUTE SENSE

- B SAME OFFICE & FIELD CALIBRATION



PASSIVE/ACTIVE

- NAD 83 REALIZED THROUGH NATIONAL CORS
- NAVD 88 REALIZED FROM PASSIVE MARKS
- NGSIDB HAS 1,000,000 PASSIVE MARKS
- PASSIVE MARKS IN STATES HAVE MANY CAMPAIGNS OVER MANY YEARS WITH MANY ACCURACIES IN MANY SEPARATE ADJUSTMENTS. RTN MAY NOT AGREE WITH THESE REQUIRING CONSTRAINTS TO THE MONUMENTS FOR PROJECT WORK.
- PASSIVE MARKS COORDINATES ARE A SNAPSHOT IN TIME AND CAN BE RELIED ON TO BE ACCURATE ONLY AT THE RECORDED OBSERVATION TIME.
- 2020+ = NEW GEOMETRIC DATUM / 1 CM GRAVIMETRIC GEOID, VELOCITIES ON A GEOCENTRIC DATUM
- THE METHOD OF CHOICE TO ACCESS THE NSRS IS ACTIVE MONUMENTATION (CORS, OPUS, RTN)

POSITIONAL ACCURACY
REPLACING DISTANCE CORRELATED ACCURACY

```
NE1027 ***********************************************************************
NE1027  CBN            -  This is a Cooperative Base Network Control Station.
NE1027  DESIGNATION -  F 337
NE1027  PID            -  NE1027
NE1027  STATE/COUNTY-  MI/WAYNE
NE1027  USGS QUAD     -  YPSILANTI EAST (1983)
NE1027
NE1027                          *CURRENT SURVEY CONTROL
NE1027
NE1027* NAD 83(2007)-  42 13 10.41682(N)    083 30 40.50685(W)     ADJUSTED
NE1027* NAVD 88       -       212.637  (meters)     697.63    (feet)  ADJUSTED
NE1027
NE1027  EPOCH DATE   -        2002.00
NE1027  X              -     534,616.161 (meters)                      COMP
NE1027  Y              -  -4,700,472.689 (meters)                      COMP
NE1027  Z              -   4,263,815.954 (meters)                      COMP
NE1027  LAPLACE CORR-          -1.96   (seconds)                       DEFLEC09
NE1027  ELLIP HEIGHT-          178.286 (meters)         (06/10/07) ADJUSTED
NE1027  GEOID HEIGHT-          -34.35  (meters)                        GEOID09
NE1027  DYNAMIC HT   -          212.570 (meters)     697.41   (feet)  COMP
```

```
NE1027                          SUPERSEDED SURVEY CONTROL
NE1027                                                                  cm) --------
                                                                         East  Ellip
NE1027  ELLIP H (02/10/07)  178.277   (m)                  GP(         )
NE1027  ELLIP H (06/11/02)  178.311   (m)                  GP(         ) 4 1   0.31   0.94
NE1027  NAD 83(1994)-  42 13 10.41653(N)  083 30 40.50656(W) AD(         ) B
NE1027  ELLIP H (09/20/95)  178.321   (m)                  GP(         ) 1 2    NAVD 88
NE1027  NAD 83(1986)-  42 13 10.42375(N)  083 30 40.53514(W) AD(         ) 1       GRAV_OBS
NE1027  NAD 83(1986)-  42 13 10.42214(N)  083 30 40.53071(W) AD(         ) 1
NE1027  NAVD 88 (09/30/94)  212.64    (m)        697.6    (f) LEVELING    3
NE1027  NGVD 29 (01/19/93)  212.768   (m)        698.06   (f) ADJUSTED    1 2   vations
NE1027                                                                          2007.
NE1027
```

Monumented Points Deterioration

Disturbed Geodetic Control
Coordinates/Elevations Questionable!

Destroyed Geodetic Control
No Coordinates/Elevation

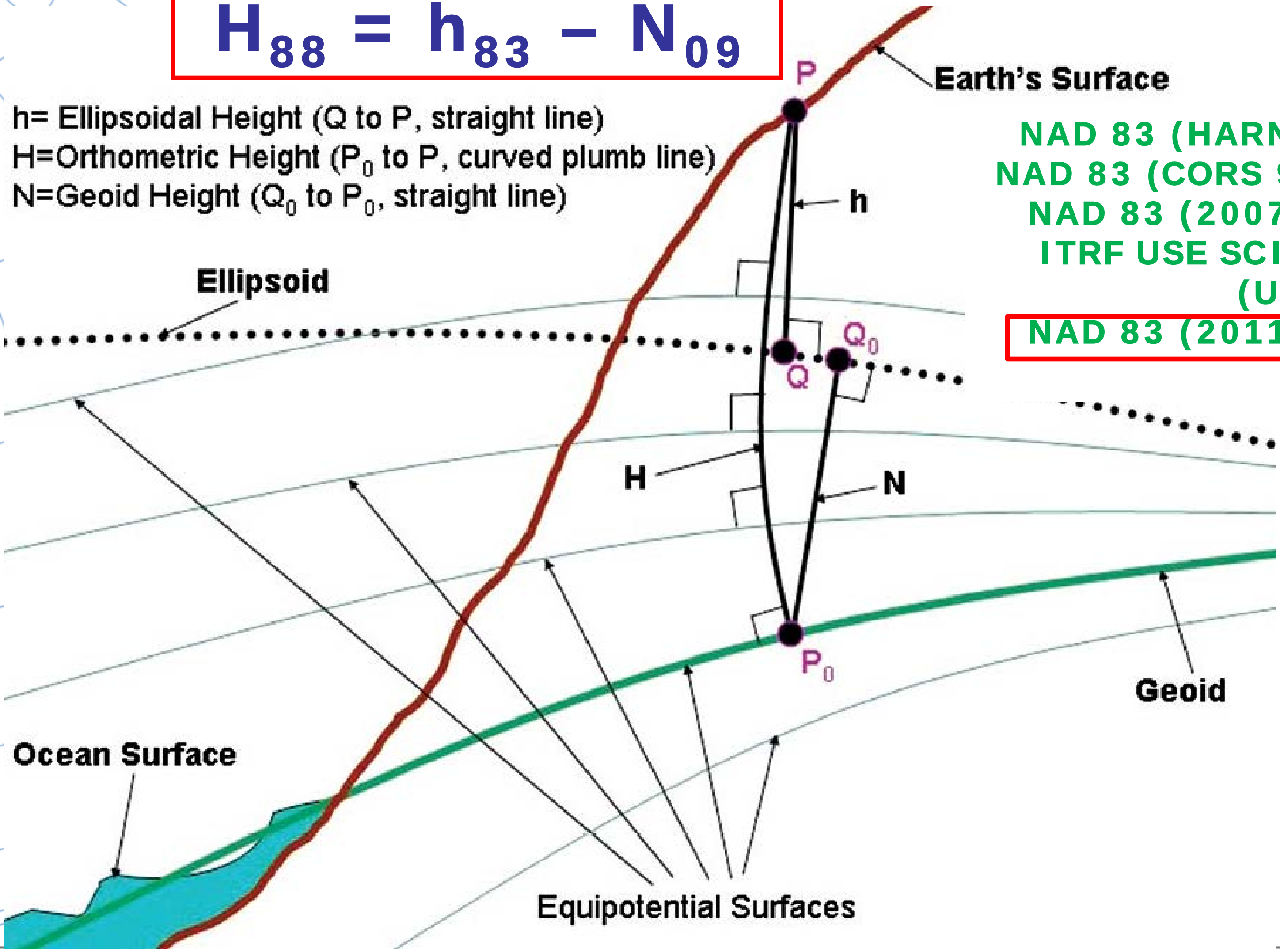
RT DERIVED ORTHO HEIGHTS - LOCALIZE OR NOT?

- PASSIVE MARKS ARE A SNAP SHOT OF WHEN THEY WERE LEVELED OR DERIVED FROM GPS
- IF YOU BUILD FROM A MONUMENTED BM AND THE DESIGN WAS DONE REFERENCED TO IT, IT IS "THE TRUTH", UNLESS IN GROSS ERROR.
- CONSTRAINING TO PASSIVE BMs IS A GOOD WAY TO NOT ONLY LOCK TO THE SURROUNDING PASSIVE MARKS, BUT ALSO TO EVALUATE HOW THE CONTROL FITS TOGETHER.
- HOW GOOD IS THE NGS HYBRID GEOID MODEL IN YOUR AREA? (SIDE NOTE: GEOID 09 IS THE CURRENT MODEL USED BY OPUS)

USING RTN ELLIPSOID HEIGHTS WITH THE HYBRID GEOID FOR ORTHO HEIGHTS

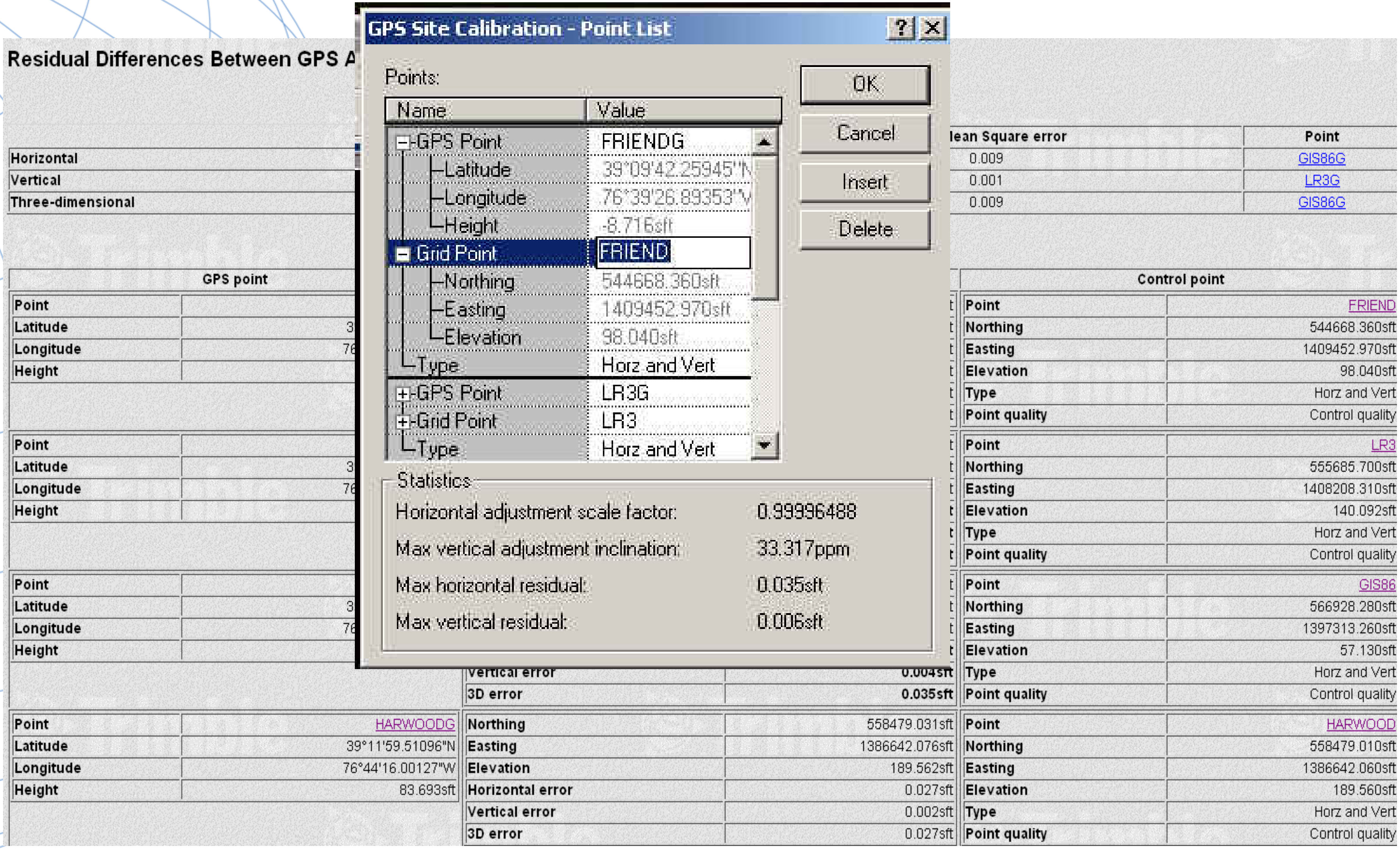
$$H_{88} = h_{83} - N_{09}$$

h= Ellipsoidal Height (Q to P, straight line)
H=Orthometric Height (P_0 to P, curved plumb line)
N=Geoid Height (Q_0 to P_0, straight line)



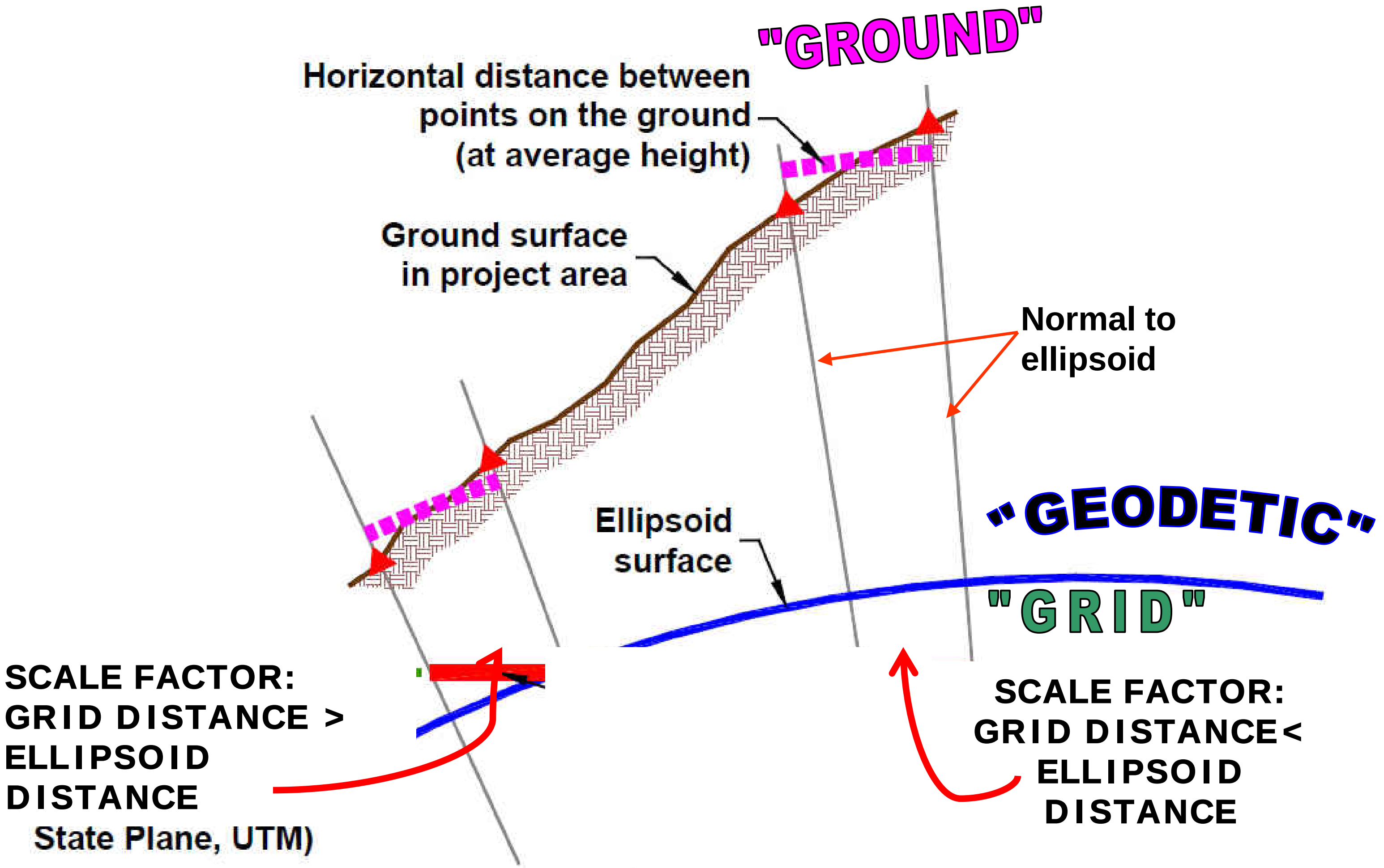
NAD 83 (HARN) USE GEOID O3
NAD 83 (CORS 96) USE GEOID 09
NAD 83 (2007) USE GEOID 09
ITRF USE SCIENTIFIC GEOID (USGG)
NAD 83 (2011) USE GEOID 12

CALIBRATIONS / VERTICAL LOCALIZATIONS



GRID/GROUND ISSUE

Linear distortion due to ground height above ellipsoid



PROJECT SURFACE VS. GRID PROJECTION SURFACE
IS YOUR DATA COLLECTOR CONFIGURED TO HANDLE THE TRANSFORMATION?

- FEATURES AND WORK ARE REFERENCED TO THE GROUND
- CONTROL MONUMENTATION IS USUALLY REFERENCED TO THE GRID
- THERE ARE DIFFERENT WAYS TO RESOLVE THIS:
  1. MODIFIED SPC
  2. LDP
  3. LOCALIZATION TO PASSIVE MONUMENTATION
  4. ASSUMED (TANGENT PLANE)

RTN CAN ENCOMPASS LARGE REGIONS COMPOSSED OF MANY STATES!

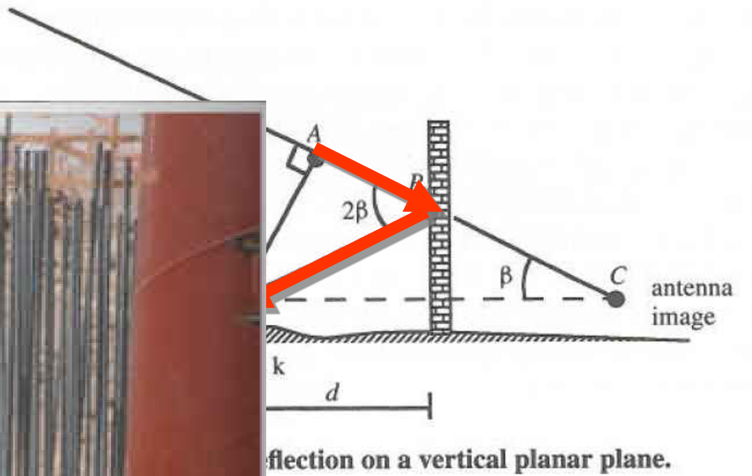
COLLECTION

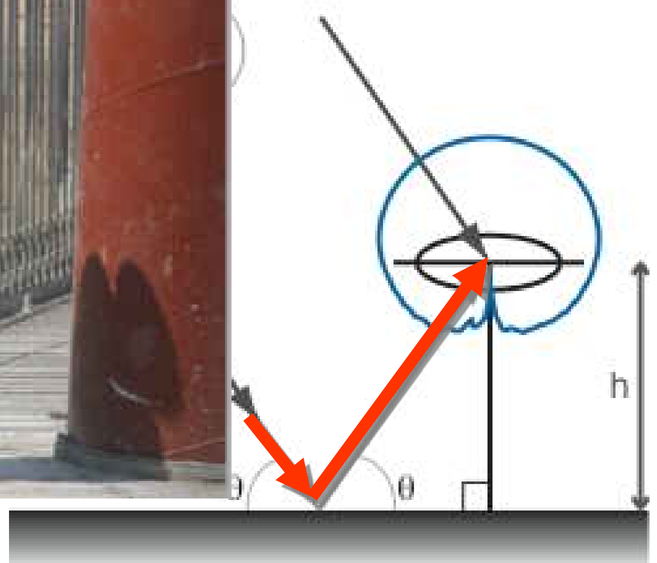
- B CHECK ON KNOWN POINTS!
- B SET ELEVATION MASK
- B ANTENNA TYPES ENTERED OK?
- B SET COVARIANCE MATRICES ON (IF NECESSARY).
- B RMS SHOWN IS TYPICALLY 68% CONFIDENCE (BRAND DEPENDENT)
- B H & V PRECISION SHOWN IS TYPICALLY 68% CONFIDENCE
- B TIME ON POINT? QA/QC OF INTEGER FIX
- B MULTIPATH? DISCRETE/DIFFUSE
- B BUBBLE LEVELED?
- B PDOP?
- B FIXED SOLUTION?
- B USE BIPOD?
- B COMMS CONTINUOUS DURING LOCATION?
- B BLUNDER CHECK LOCATION ON IMPORTANT POINTS.

COLLECTION ENVIRONMENT

- WHAT ABOUT TREE CANOPY?
- WHAT ABOUT HIGH POWER TRANSMISSION LINES?
- WHAT ABOUT SNOW AND RAIN?
- WHAT ABOUT KINEMATIC PP WHERE COMMUNICATION IS LOST FOR A SHORT TIME?
- WHAT ABOUT LASER RANGE FINDERS?
- WHAT ABOUT INCLINOMETERS?

MULTIPATH





= EXTRA DISTANCE

MULTIPATH = NOISE
SPECULAR(DISCRETE) & DIFFUSE

INSIDE GNSS

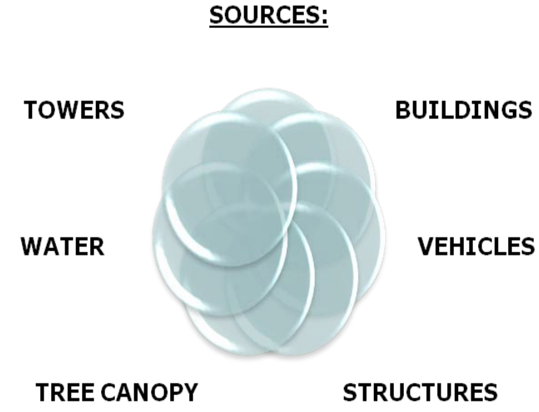
NOVEMBER-DECEMBER 2008

"MULTIATH-MITIGATION TECHNIQUES USING MAXIMUM-LIKELIHOOD PRINCIPLE"

MOHAMED SAHMOUDI AND

RENE JR. LANDRY

WWW.INSIDEGNSS.COM



NOTE:
Newer antennas have much better multipath mitigation / rejection than legacy antennas

$$\varphi_k^p(t) = \frac{f}{c}\rho_k^p(t) - f dt_k(t) + f dt^p(t) + N_k^p - I_{k,\varphi}^p(t) + \frac{f}{c}T_k^p(t) + d_{k,\varphi}(t) + d_{k,\varphi}^p(t) + d_\varphi^p(t) + \varepsilon_\varphi$$

CONFIDENCE

- B **CHECK** KNOWN BEFORE, DURING, AFTER SESSION.
- B NECESSARY REDUNDANCY? (U. of

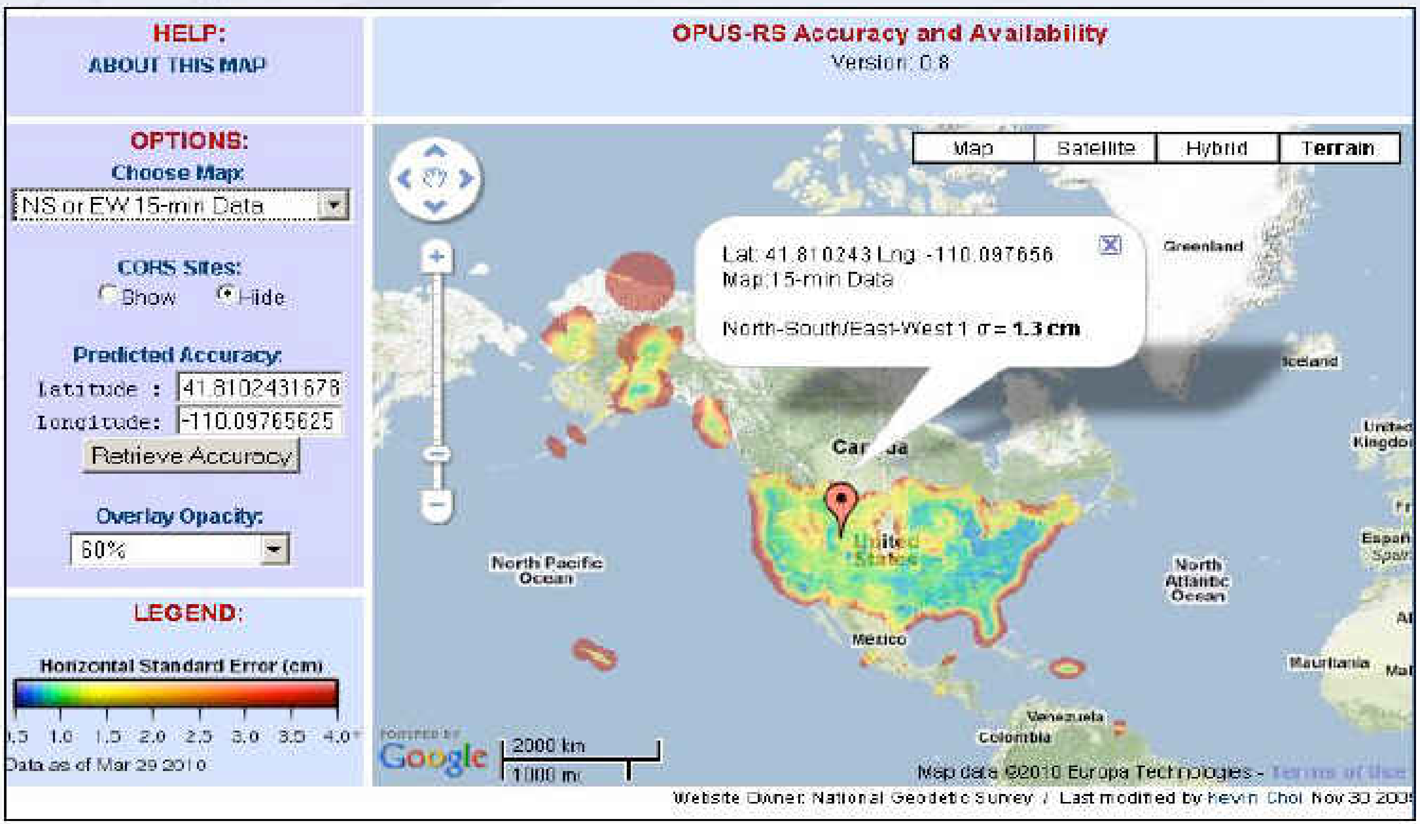
CAN'T INITIALIZE? BAD CHECKS? PLENTY OF SATS? TRY:
▪TURN OFF GLONASS IF YOU HAVE ≥6 COMMON GPS SATS
▪REININTIALIZE
▪CHECK FOR "NOISY" SATS IN DATA COLLECTOR
▪LOOK FOR MULTIPATH NEARBY

- B BE AWARE OF POTENTIAL INTERFERENCE (E.G., HIGH TENSION TOWER LINES)

BLUNDER/MISMATCH CHECKING

How Good Can I Do With OPUS-RS?

The OPUS-RS Accuracy and Availability Tool.

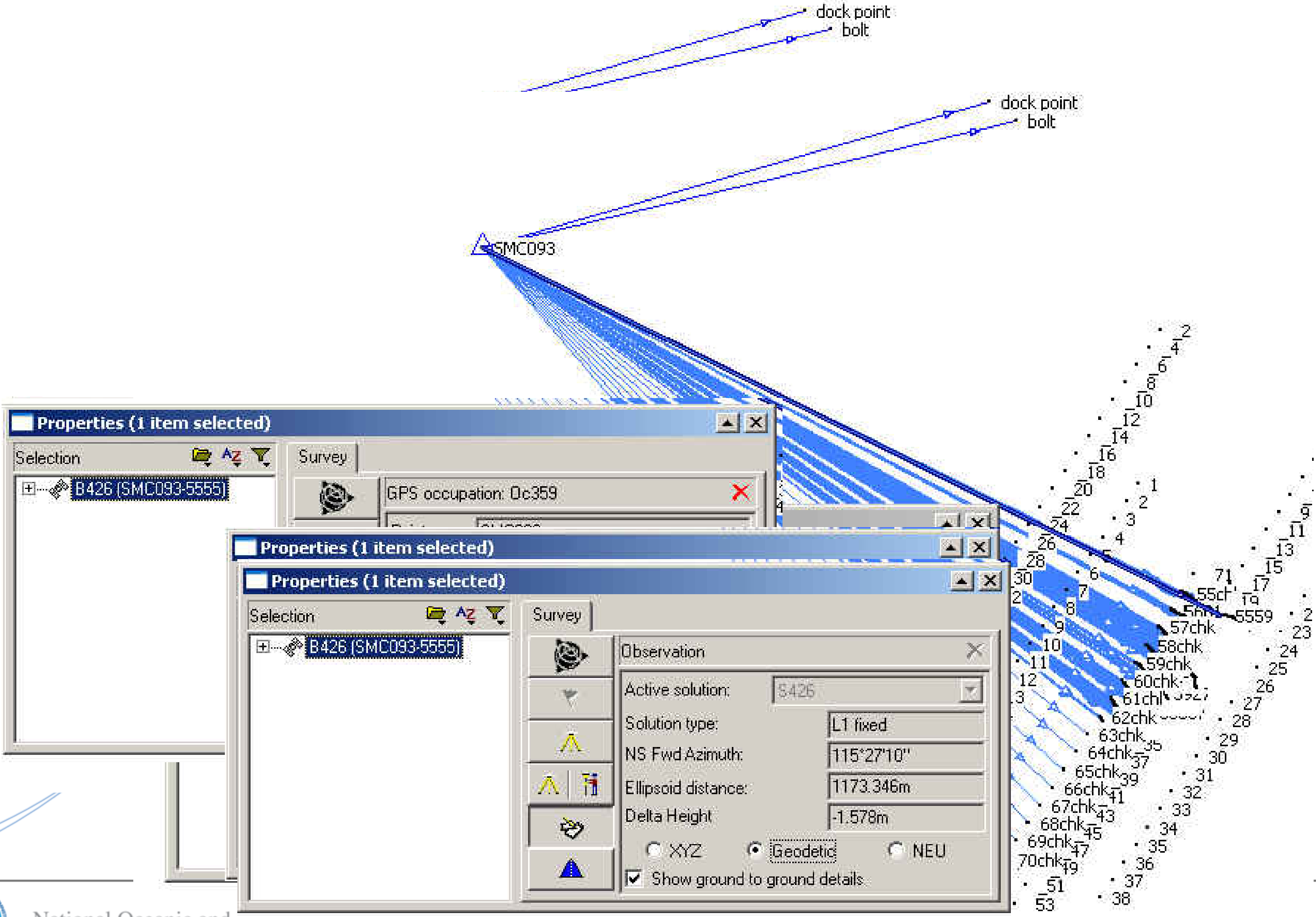


http://www.ngs.noaa.gov/OPUSI/Plots/Gmap/OPUSRS_sigmap.shtml

FURTHER CHECKS IN THE OFFICE

- Antenna heights (height blunders are unacceptable and can even produce horizontal error - Meyer, et.al, 2005).
- Antenna types
- RMS values
- Redundant observations
- Horizontal & vertical precision
- PDOP
- Base station coordinates
- Number of satellites
- Calibration (if any) residuals

VECTOR & EQUIPMENT REVIEW



METADATA !

BESIDES ATTRIBUTE FIELDS, THE RT PRACTICIONER MUST KEEP RECORDS OF ITEMS NOT RECORDED IN THE FIELD, FOR INSTANCE:

- ✓ WHAT IS THE SOURCE OF THE DATA?
- ✓ WHAT WAS THE DATUM / ADJUSTMENT / EPOCH?
- ✓ WHAT WERE THE FIELD CONDITIONS?
- ✓ WHAT EQUIPMENT WAS USED, ESPECIALLY- WHAT ANTENNA?
- ✓ WAS COMMUNICATION SOLID?
- ✓ WHAT FIRMWARE WAS IN THE RECEIVER & COLLECTOR?
- ✓ WERE ANY GUIDELINES USED FOR COLLECTION?
- ✓ WHAT REDUNDANCY, IF ANY, WAS USED?
- ✓ WERE ANY PASSIVE MARKS CONSTRAINED?

(GOOD IDEA TO CREATE A TABLULAR CHECK LIST FORM)

KNOW YOUR METADATA

ALL THESE COME INTO PLAY TO ENABLE THE STRUCTURE TO CLEAR THE BRIDGE!

↓

- LMSL
- NAD 83
- NAVD 88
- BATHYMETRY
- CHART DATUM
- BRIDGE DYNAMICS
- BRIDGE DIMENSIONS
- SHIP SQUAT
- SHIP DIMENSIONS

QUICK FIELD SUMMARY:

- Set the base at a wide open site
- Set rover elevation mask between 10° & 15°
- The more satellites the better
- The lower the PDOP the better
- The more redundancy the better
- Beware multipath
- Beware long initialization times
- Beware antenna height blunders
- Survey with “fixed” solutions only
- Always check known points before, during and after new location sessions
- Keep equipment adjusted for highest accuracy
- Communication should be continuous while locating a point
- Precision displayed in the data collector can be at the 68 percent level (or 1σ), which is only about half the error spread to get 95 percent confidence
- Have back up batteries & cables
- RT doesn’t like tree canopy or tall buildings

FOUR CARDINAL RULES FOR RT POSITIONING

- COMMUNICATIONS: THE KEY TO SUCCESS
- CHECK SHOT: FIRST BEFORE NEW WORK
- REDUNDANCY: FOR CONFIDENCE
- MULTIPATH: AVOID UNSUITABLE CONDITIONS

CRADLE TO GRAVE GNSS!

GPS Helps Track Babies in Nurseries
Hospitals all over the world are starting to use GPS to track newborns in their nurseries as a security measure.

Instead of looking for a traditional tombstone to mark the final resting place of a loved one, friends and relatives will be able to find the location of the deceased using a GPS device or mobile phone.
"The park will look very natural, just grass and trees. There will be no headstones and instead people will be buried in the park and a GPS locator placed in the coffin," Michael McMahon chief executive of the Catholic Cemeteries Board told ABC News.