

GPS BASICS: LEARNING HOW GPS WORKS & HOW TO USE IT CORRECTLY



MSS 2014 PART 1: THE GPS SYSTEM WITH CODE PHASE AND CARRIER PHASE POSITIONING

ALAN DRAGOO
Prop LS.

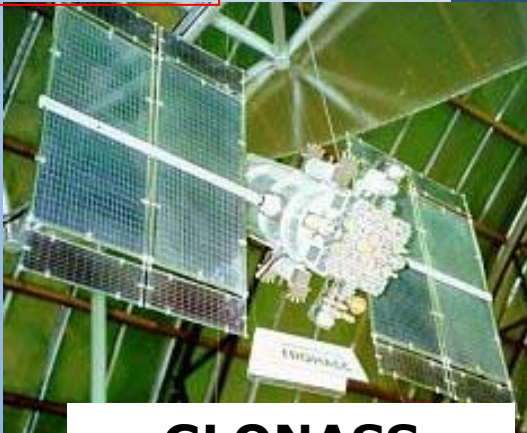


BILL HENNING,
Prof LS.



"GNSS"

24



GLONASS

**RUSSIAN AEROSPACE
DEFENSE FORCES**

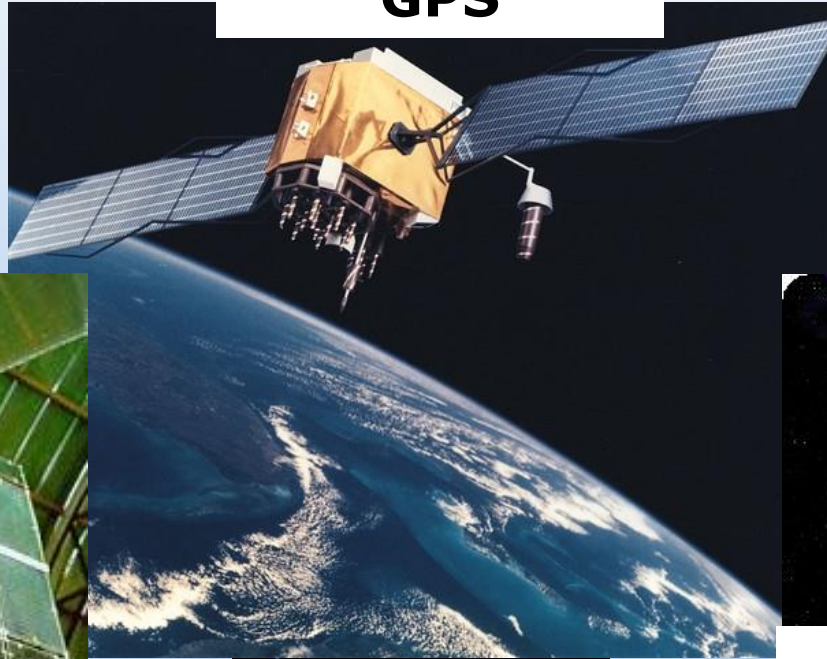
30



COMPASS (BEIDOU-2)

**CHINESE NATIONAL SPACE
ADMINISTRATION**

GPS



32

DEPT. OF DEFENSE

GALILEO



30

EU & ESA

GPS GROWTH

2000

**1.5 MILLION
USERS
ECONOMIC
IMPACT = \$6.2
BILLION**



2010

**1 BILLION USERS
1 BILLION
RECEIVERS
ECONOMIC
IMPACT = \$50
BILLION**

(Source: University of Washington Olympic Natural Resources Center.)

A SHORT HISTORY OF GPS DEVELOPMENT

- 1956 – Friedwart Winterberg (theoretical physicist at U of NV) proposed test of general relativity using atomic clocks in satellites
- 1958 – Two American Physicists: William Guier & George Weiffenbach (JHAPL), monitor Sputnik using Doppler effect principles of its radio signal to compute its orbit using UNIVAC II, leading to the development of the Navy TRANSIT system 1964-1996(using the reverse solution).
- 1960 – First Navy TRANSIT satellite launched. System of 5 satellites with 1 fix/hour.
- 1963 – Air Force “Project 57” 3-D LORAN-like system study births the GPS concept.
- 1967 – Navy places atomic clocks in space
- Cold war arms race drives research using billions of dollars for precise navigation for: submarine ballistic missiles, strategic bombers, and ICBMs.

A SHORT HISTORY of GPS DEVELOPMENT

Generalized Development Model (GDM)

- Labor day Weekend, 1973 – 12 military officers meet at the Pentagon & create the “Defense Navigation Satellite System” (DNSS)- renamed NAVSTAR.
- 1978 – First experimental Block I GPS satellite launched
- 1983 – President Reagan issues directive to make GPS freely available for public use, after Korean flight 007 shot down over Russian airspace.
- 1985 – GPS command & control center moved to 2nd Satellite Control Squadron at Falcon AF Station in Colorado Springs (now “Schriever”). 10 Block I satellites in orbit.
- February 14, 1989 – First Block II satellite launched
- 1990-1 – Gulf war is first conflict where GPS is used.
- 1993 – 24 satellites in orbit
- April 1995 – Full operational capability declared by Air Force Space Command.

Avionics Division of Rockwell International). It weighed more than 270 pounds and was contained in the Air Force equipment flight test pallet and behind the seating and air conditioning pallet.

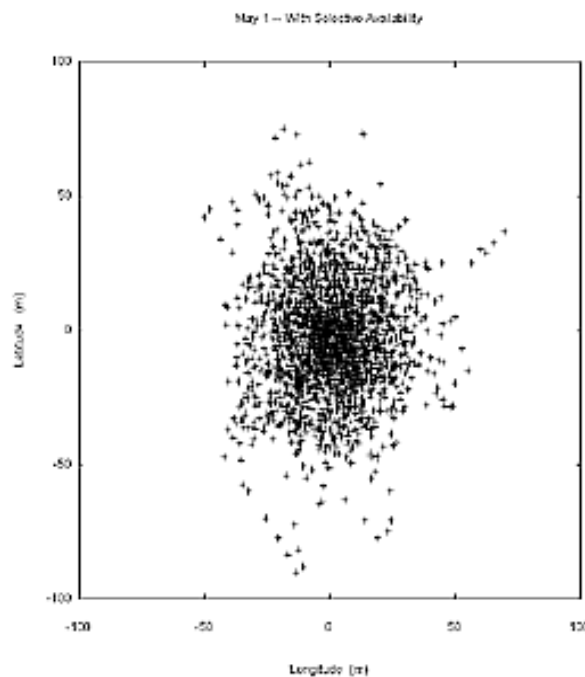
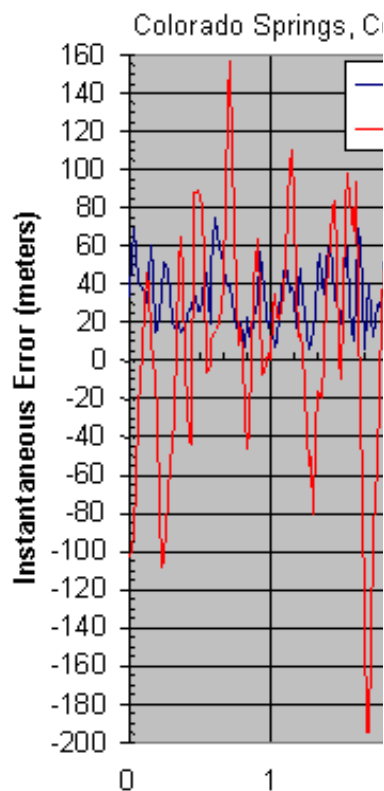


SA Transition -- 2 May 2000

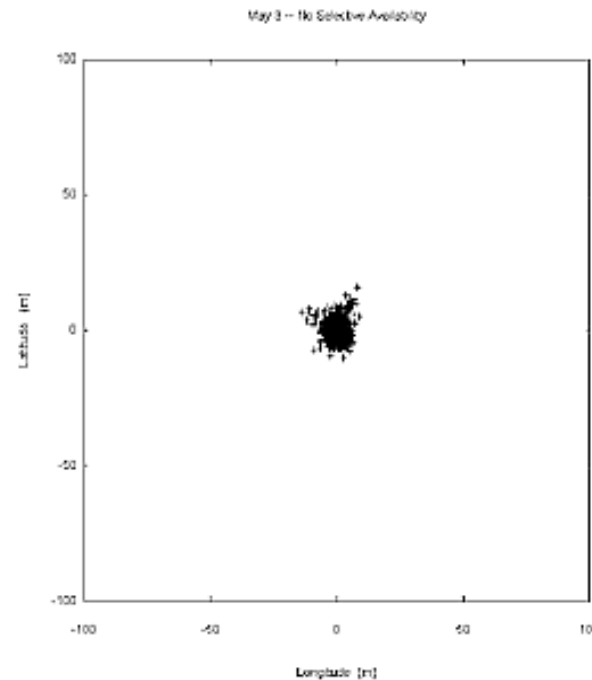
ENT

GPS Accuracy Before and After SA Removal

NOAA National Geodetic Survey [\[link\]](#)



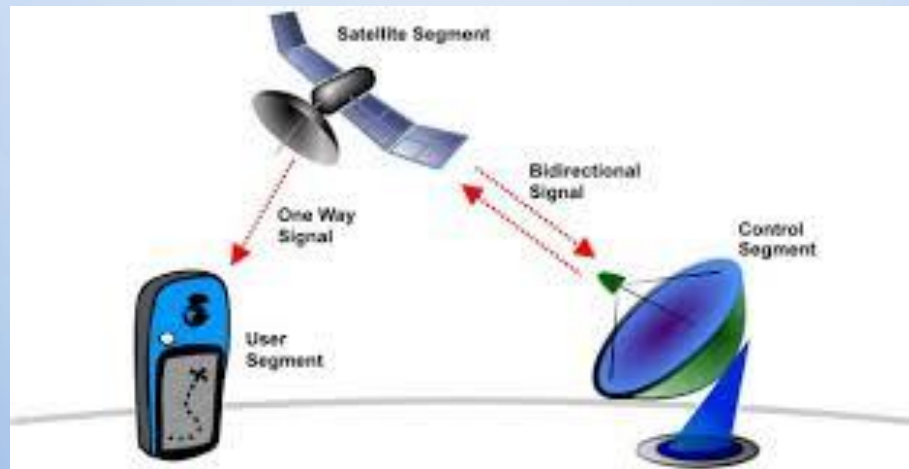
May 1, 2000



May 3, 2000

GPS USES THREE SEGMENTS:

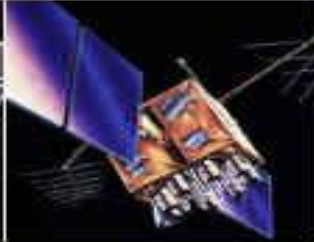
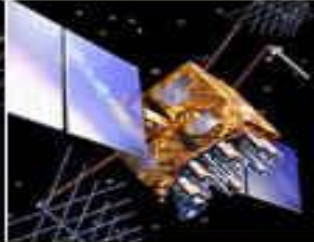
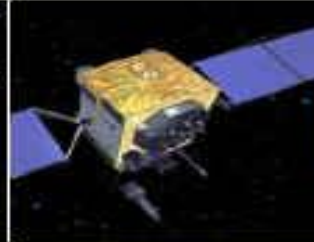
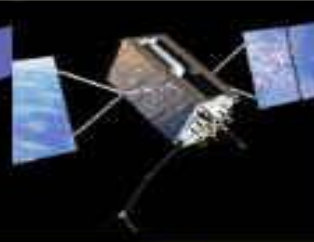
SPACE = THE CONSTELLATION OF SATELLITES TRANSMITTING INFORMATION



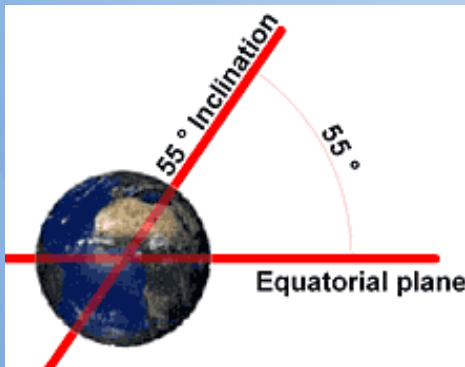
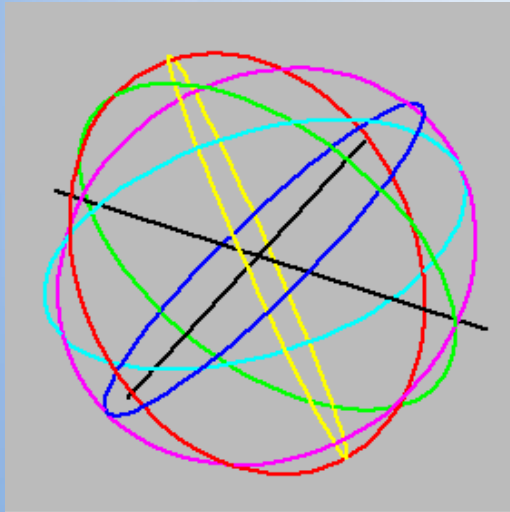
GROUND = MONITORING, COMMAND AND CONTROL OF THE CONSTELLATION

USER = CIVIL AND MILITARY RECEIVERS

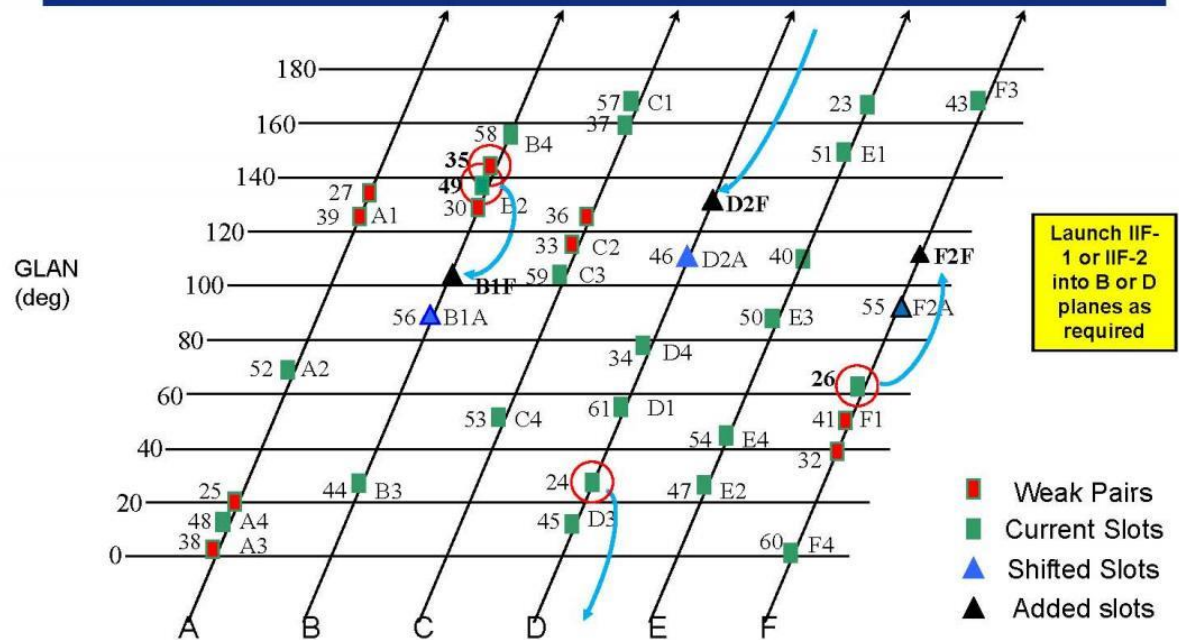
SPACE SEGMENT: LAUNCH HISTORY

LEGACY SATELLITES		MODERNIZED SATELLITES		
				
BLOCK IIA	BLOCK IIR	BLOCK IIR(M)	BLOCK IIF	GPS III
6 operational	12 operational	7 operational	6 operational	Now in production
▪ Coarse Acquisition (C/A) code on L1 frequency for civil users ▪ Precise P(Y) code on L1 & L2 frequencies for military users ▪ 7.5-year design lifespan ▪ Launched in 1990-1997	▪ C/A code on L1 ▪ P(Y) code on L1 & L2 ▪ On-board clock monitoring ▪ 7.5-year design lifespan ▪ Launched in 1997-2004 VIEW AIR FORCE FACT SHEET ➔	▪ All legacy signals ▪ 2nd civil signal on L2 (L2C) LEARN MORE ➔ ▪ New military M code signals for enhanced jam resistance ▪ Flexible power levels for military signals ▪ 7.5-year design lifespan ▪ Launched in 2005-2009 VIEW AIR FORCE FACT SHEET ➔	▪ All Block IIR(M) signals ▪ 3rd civil signal on L5 frequency (L5) LEARN MORE ➔ ▪ Advanced atomic clocks ▪ Improved accuracy, signal strength, and quality ▪ 12-year design lifespan ▪ Launched since 2010 VIEW AIR FORCE FACT SHEET ➔	▪ All Block IIF signals ▪ 4th civil signal on L1 (L1C) LEARN MORE ➔ ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability LEARN MORE ➔ ▪ Satellites 9+: laser reflectors; search & rescue payload ▪ 15-year design lifespan ▪ Begins launching in 2016 VIEW AIR FORCE FACT SHEET ➔

GPS ORBITAL PLANES & SLOTS



Expand to 24+3 in B/D/F Planes



Integrity - Service - Excellence

GPS NAVIGATION MESSAGE

Each 30 second frame begins precisely on the minute or half minute as indicated by the atomic clock on each satellite.

The first part encodes the **week number** and the **time** within the week, as well as the **health** of the satellite. The second part of the message, the **ephemeris**. The last part of the message, the **almanac**, contains coarse orbit and status information for all satellites in the network as well as data related to error correction.

Signals are encoded using **code division multiple access** (CDMA) allowing messages from individual satellites to be distinguished from each other based on **unique encodings** for each satellite (that the receiver must be aware of). Two distinct types of CDMA encodings are used: the coarse/acquisition (C/A or **civil**) code, and the **precise** (P) code, that is encrypted so that only the U.S. military can access it.

The ephemeris is updated every **2** hours and is generally valid for 4 hours. The almanac is updated typically every **24** hours.

GPS NAVIGATION MESSAGE

Outline of Navigation Messages

Bit rate	50 bps (bit/s)
Data Structure	1500 bit/Frame · · · 30 seconds/Frame Period (12.5 minutes) 25 Frames
Main Contents of the Message	• Ephemeris (Precise Orbit Elements) • Clock Correction Coefficients (Difference from GPS time) • Ionospheric Delay Correction Data • Almanac (Approximate Orbit Elements for the other Satellites)

GPS message

Subframes	Content
1	Satellite GPS time
2-3	Ephemeris (precise)
4-5	Almanac component (satellite network synopsis, error correction)



Second Civil Signal (L2C)

- **Designed to meet commercial needs**
 - Higher accuracy via ionospheric correction
 - Expected to generate over \$5B in user productivity benefits
- **Available since 2005**
- **On 24 satellites by 2016**



Benefits existing professional receivers



Increases accuracy for consumers



Supports miniaturization, possible indoor use



Third Civil Signal (L5)

- **Designed to meet demanding requirements for transport safety**
 - Uses highly protected Aeronautical Radionavigation Service (ARNS) band
- **May also enable global, centimeter-level accuracy using new techniques**
- **Opportunity for international interoperability**
- **Demonstration signal launched in MAY 2010**
- **24 satellites by 2018**





Fourth Civil Signal (L1C)



Under trees



Urban Canyons

- **Designed with international partners for interoperability**
- **Modernized civil signal at L1 frequency**
 - More robust navigation across a broad range of user applications
 - Improved performance in challenged tracking environments
 - Original signal retained for backward compatibility
- **Launches with GPS III in 2014**
- **Transmitted from 24 satellites by ~2021**

NEW SIGNALS BOTTOM LINE:

L₅ (1176.45 MHz) , L₂C (NEW CIVIL CODE)

- More **robust**
- **Faster AR**
- Stronger signal - lower carrier-to-noise-density ratio (c/n_0) values than would otherwise be possible.
- Better signal tracking & differentiation especially at lower elevations means **better code positioning under canopy** (the better cross-correlation performance means that the reception of weak gps signals is much less affected by simultaneously received strong gps signals, which can be of significant advantage in difficult signal reception conditions.)
- Code **iono error mitigation** using L1 C/A, L2C, & P2 differencing (eventually L5 on block IIF & L1C on block III)
- **Longer baseline solutions**
- improved QA/QC with additional frequency checking
- **Faster, more accurate NAV** updates
- L2C has similar multipath characteristics as L1 C/A

GPS TIME

ORIGIN = JANUARY 1, 1980, ATOMIC TIME

DELAYED 19 SECONDS TO TAI AT ORIGIN (CONSTANT)

UTC IS CURRENTLY DELAYED 15 SECONDS TO GPS TIME

**TIME OF WEEK IN SECONDS FROM SUNDAY MORNING
THROUGH SATURDAY NIGHT = 604799 SECONDS**

**GPS PASSED THROUGH ITS 1 BILLIONTH SECOND
SEPTEMBER 14TH (2011). PROCESSING PROBLEMS?**

**GPS WEEK ROLLOVER: 8/15/99 = WEEK 1022
8/22/99 = WEEK 0
9/18/11 = WEEK 630 (1654)**

GNSS Calendar

Click on a date in one of the calendars to display data

Friday, October 3, 2014 (UTC)

Julian Day Number: **2456933.5**

Day of Year: **276**

GPS Week: **1812**

GPS Week Number: **18125**

JANUARY 2014

Su	M	Tu	W	Th	F	Sa
		1	2	3	4	
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

FEBRUARY 2014

Su	M	Tu	W	Th	F	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	

MARCH 2014

Su	M	Tu	W	Th	F	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

APRIL 2014

Su	M	Tu	W	Th	F	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

MAY 2014

Su	M	Tu	W	Th	F	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

JUNE 2014

Su	M	Tu	W	Th	F	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

JULY 2014

Su	M	Tu	W	Th	F	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

AUGUST 2014

Su	M	Tu	W	Th	F	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

SEPTEMBER 2014

Su	M	Tu	W	Th	F	Sa
1	2	3	4	5	6	
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

OCTOBER 2014

Su	M	Tu	W	Th	F	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

NOVEMBER 2014

Su	M	Tu	W	Th	F	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

DECEMBER 2014

Su	M	Tu	W	Th	F	Sa
1	2	3	4	5	6	
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

<http://www.rvdi.com/freebies/gpscalendar.html>

Calendar

data for each day are as follows:

**"JULIAN DAY
NUMBER"
IS TERRESTRIAL
TIME SINCE JAN.1,
4713 B.C. AT NOON**

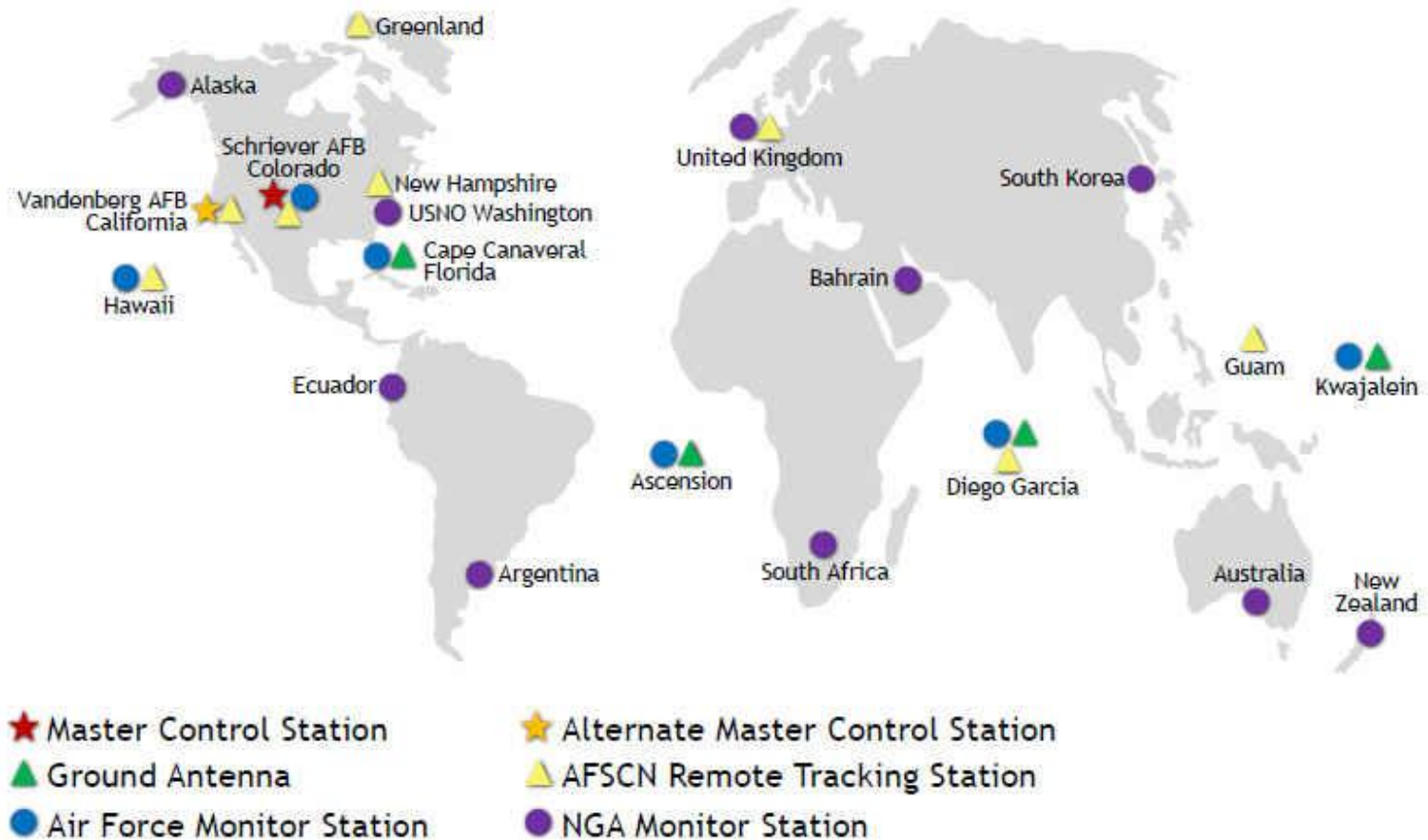
day

November		
Thu	Fri	Sat
2 1812:4 788:345600 275	3 1812:5 788:432000 276	4 1812:6 788:518400 277
9 1813:4 789:345600 282	10 1813:5 789:432000 283	11 1813:6 789:518400 284
16 1814:4 790:345600 289	17 1814:5 790:432000 290	18 1814:6 790:518400 291
23 1815:4 791:345600 296	24 1815:5 791:432000 297	25 1815:6 791:518400 298
30 1816:4 792:345600 303	31 1816:5 792:432000 304	

<http://adn.agi.com/GNSSWeb/>

GROUND CONTROL SEGMENT

GPS Control Segment



SOURCE: GPS.GOV

Updated April 2014

FUNCTIONS OF THE GROUND SEGMENT



Satellite-tracking-station on Hawaii
(Source: Schriever Air Force Base Satellite
Flyer Vol. 6; No.12)

Diagram Source: [GPS System Segments](#)

Arthur J. Dorsey and Willard A. Marquis

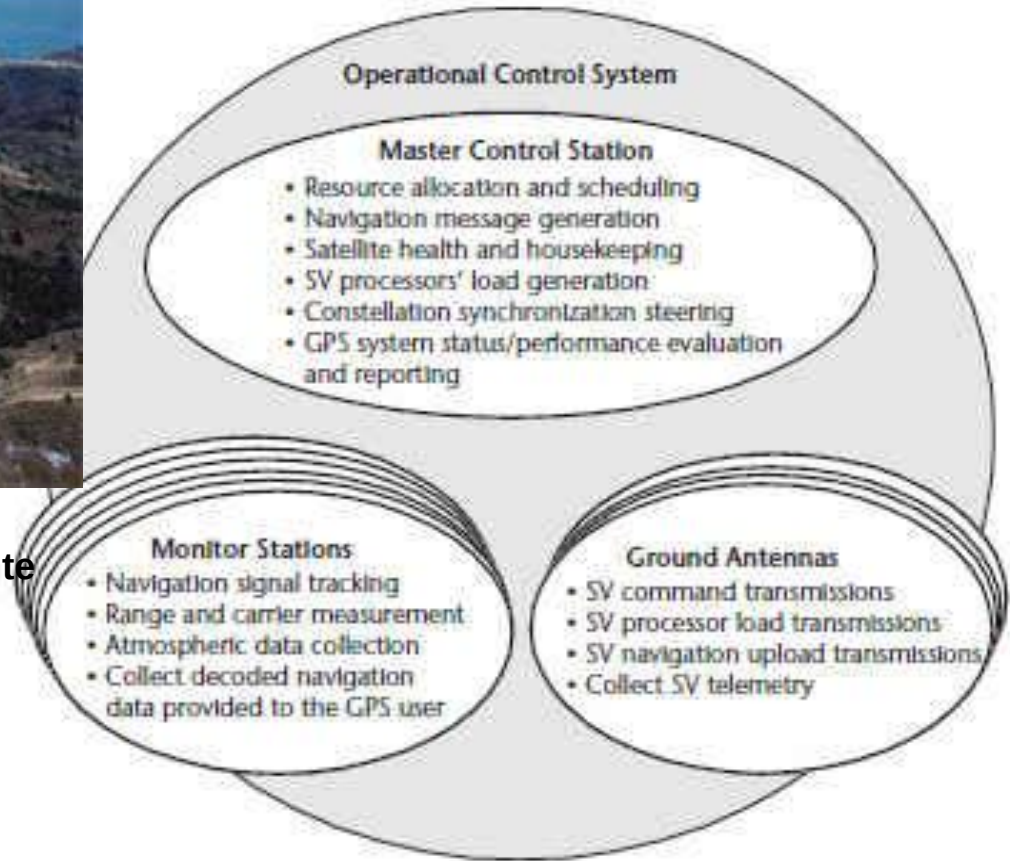
Lockheed Martin Corporation

Peter M. Fyfe

The Boeing Company

Elliott D. Kaplan and Lawrence F. Wiederholt

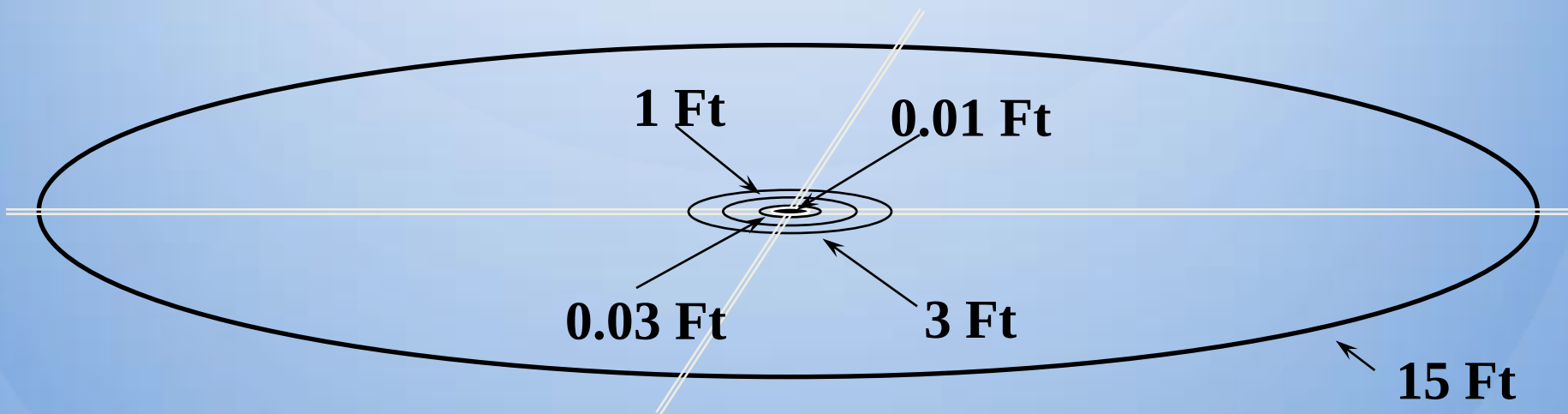
The MITRE Corporation



GPS USERS SEGMENT

- **SURVEYING/ENGINEERING, BUT SOME OTHER VERY IMPORTANT APPS:**
- **PRECISION AGRICULTURE AND MACHINE GUIDANCE**
- **REMOTE SENSING, UAS**
- **CELLULAR NETWORKS**
- **BANKING- \$\$ TRANSFERS/ATMS**
- **POWER GRIDS**
- **TRANSPORTATION- SHIPS/RAIL/TRUCKS**
- **EMERGENCY MANAGEMENT**
- **WEATHER PREDICTION**
- **DEFORMATION MODELING**
- **CRUSTAL MOTION & OTHER SCIENTIFIC APPS**
- **“GRACE” POSITIONS FOR HIGH DEF. GRAVITY= NEW GEOPOTENTIAL DATUM FOR US!**

What Accuracy Do You Need?
What Confidence Level Do You Need?



**So What Tool Are You
Going To Use To Get
There?**

EXPANDING GPS MARKETS



MACHINE GUIDANCE



**MOBILE
MAPPING
SYSTEMS**

Advanced Farming Systems

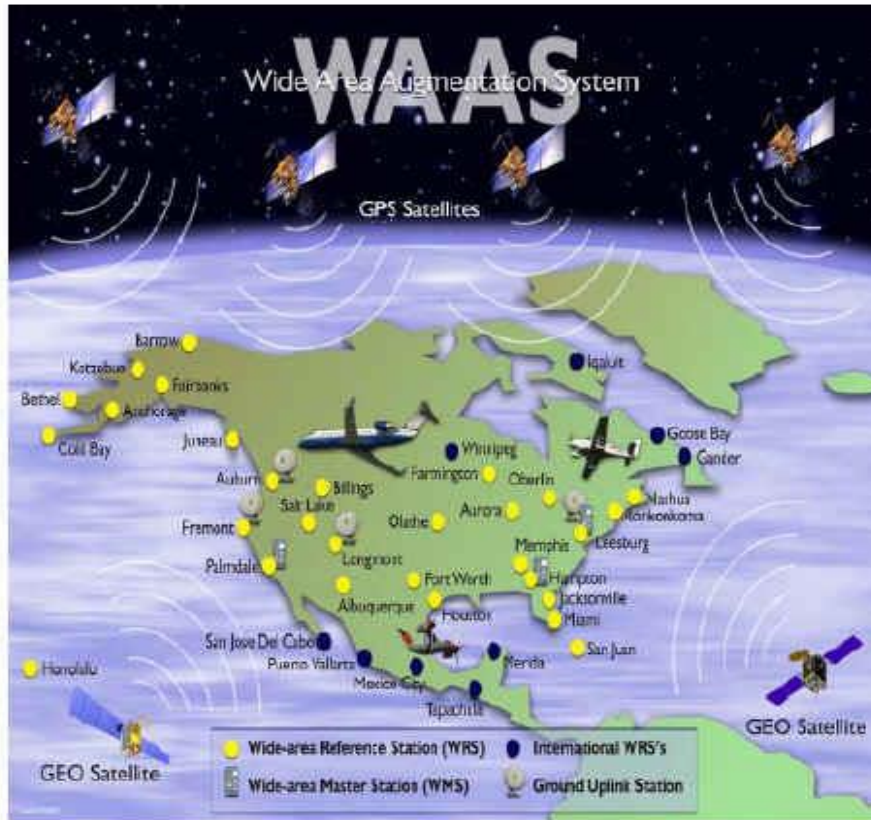


GIS INFRASTRUCTURE

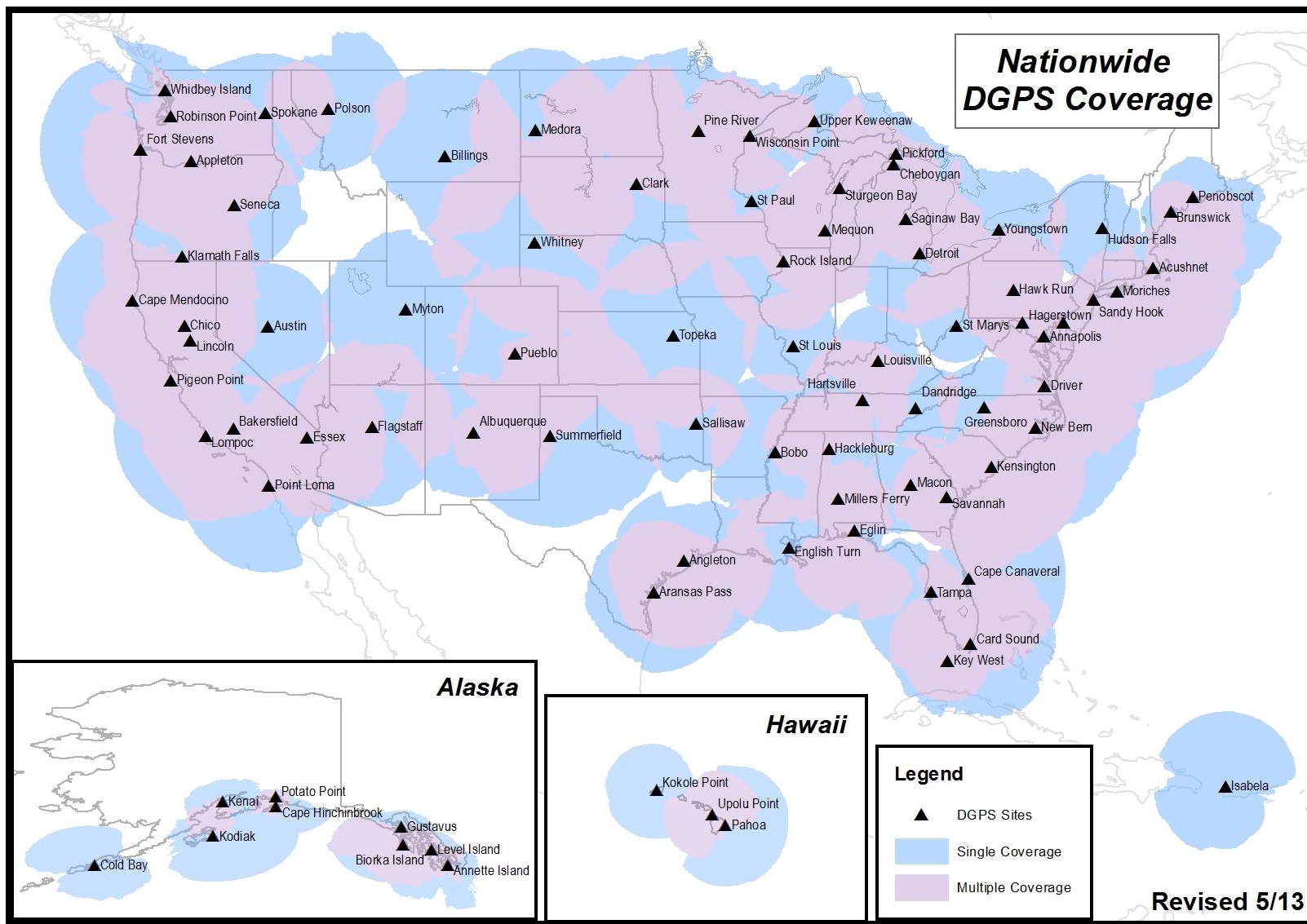
AUGMENTING GPS: SBAS

WAAS Architecture

BETTER THAN "COUPLA" METERS



AUGMENTING GPS: DGPS



GPS SIGNALS- CODE PHASE

36 suitable codes are referred to as GOLD-codes (names after a mathematician). For these GOLD-codes the correlation among each other is particularly weak, making an unequivocal identification possible.

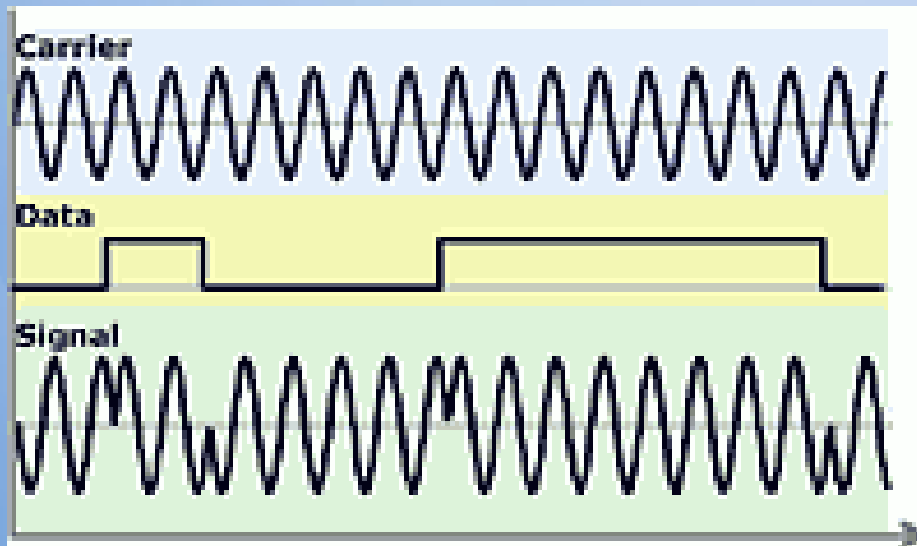
Navigation Data–50Hz Data, –Satellite Almanac, –Satellite Ephemeris,–Satellite Clock Error –GPS Time to UTC– Ionosphere Model parameters–User Range Accuracy(URA)

CODE *MODULATES* THE CARRIER WAVE

PHASE MODULATION:

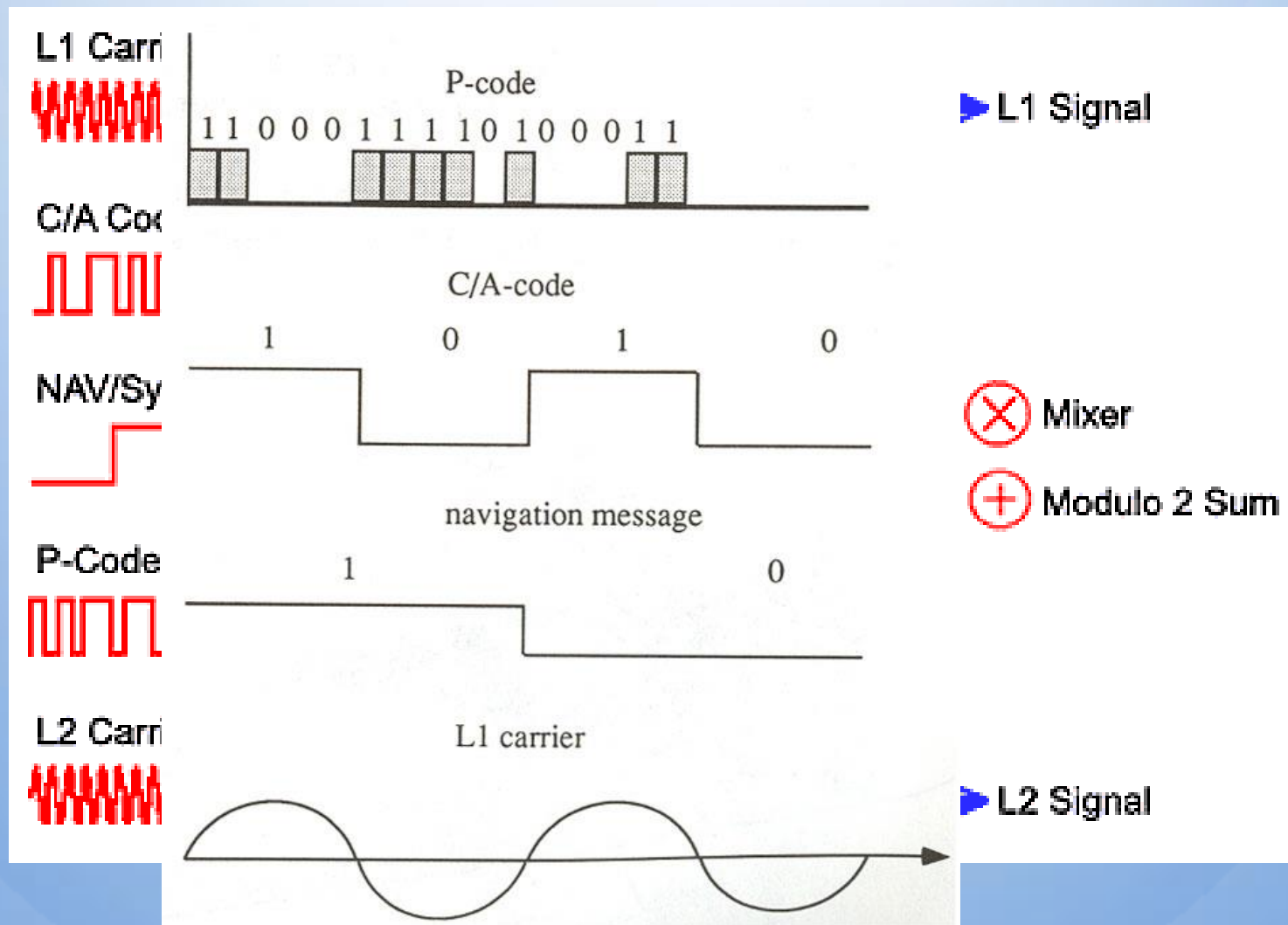
When a data signal shall be modulated onto a carrier signal by phase modulation, the sine oscillation of the carrier signal is interrupted and restarted with a **PHASE SHIFT OF 180°**. This phase shift can be recognized by a suitable receiver and the data can be restored. Phase modulation leads to an extension of the frequency range of the carrier signal (leading to a spread spectrum) depending on how often the phase is shifted. When the phase changes, wave peaks are followed by wave minimums in a shorter distance than were in the original carrier signal (as can be seen in the graph).

This kind of modulation can only be used for the transmission of digital data.

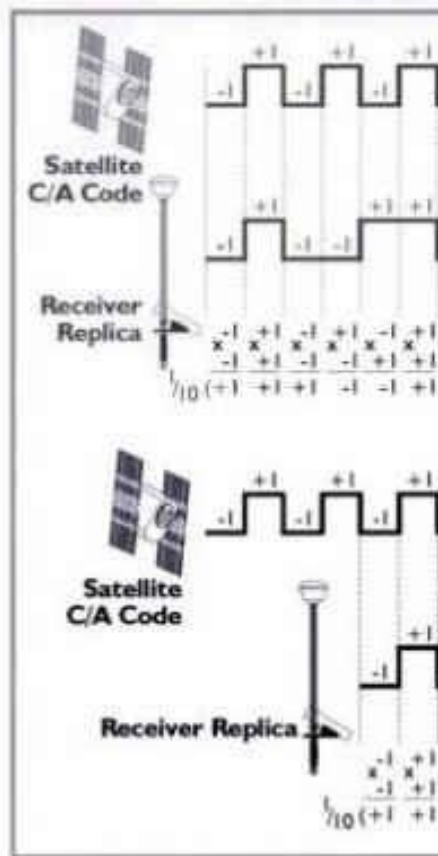


SOURCE:<http://www.kowoma.de/en/gps/signals.htm>

GPS SIGNAL STRUCTURE



PRN CODE MODULATION



Fig

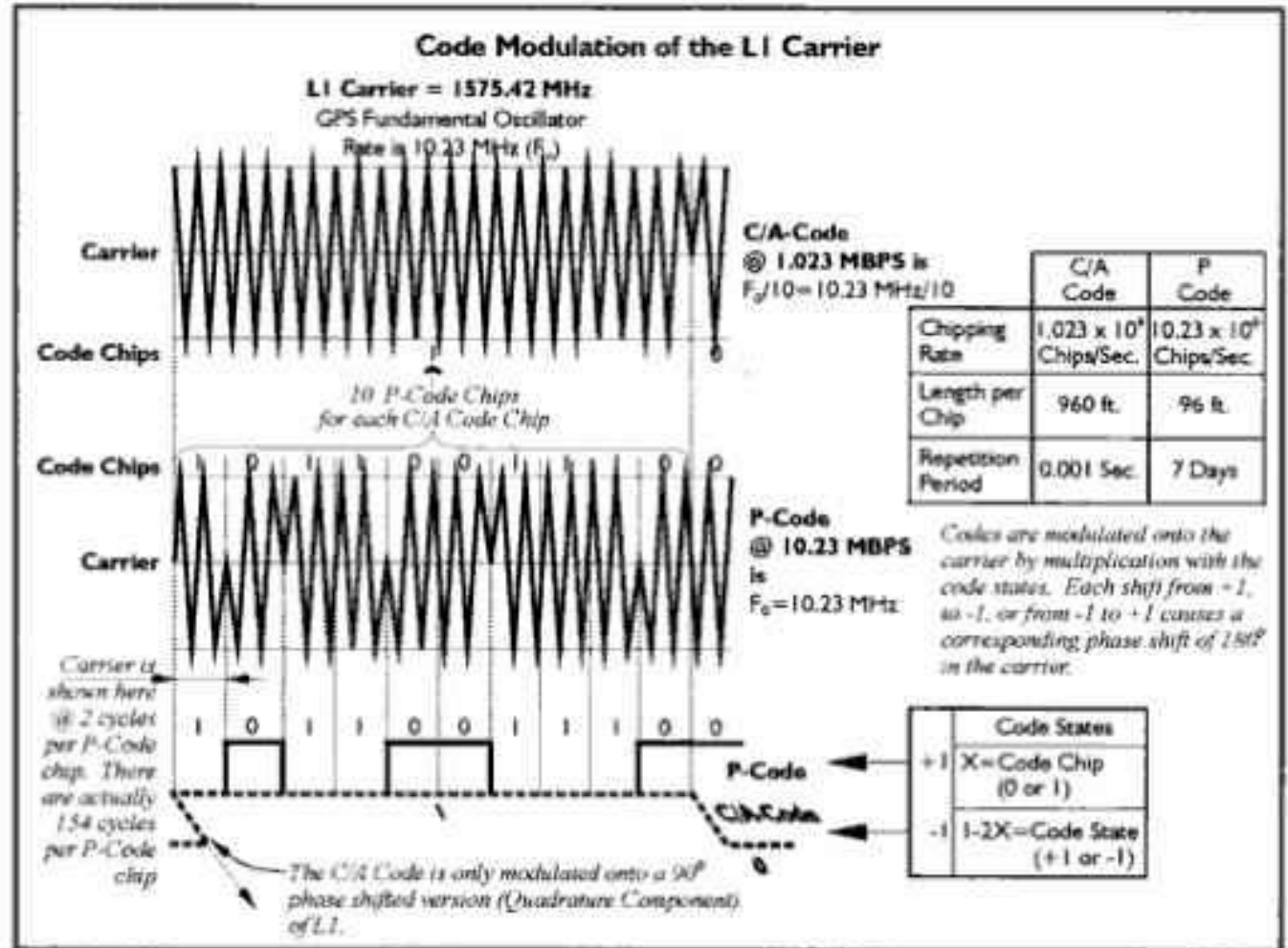


Figure 1.7. Code Modulation of the L1 Carrier.

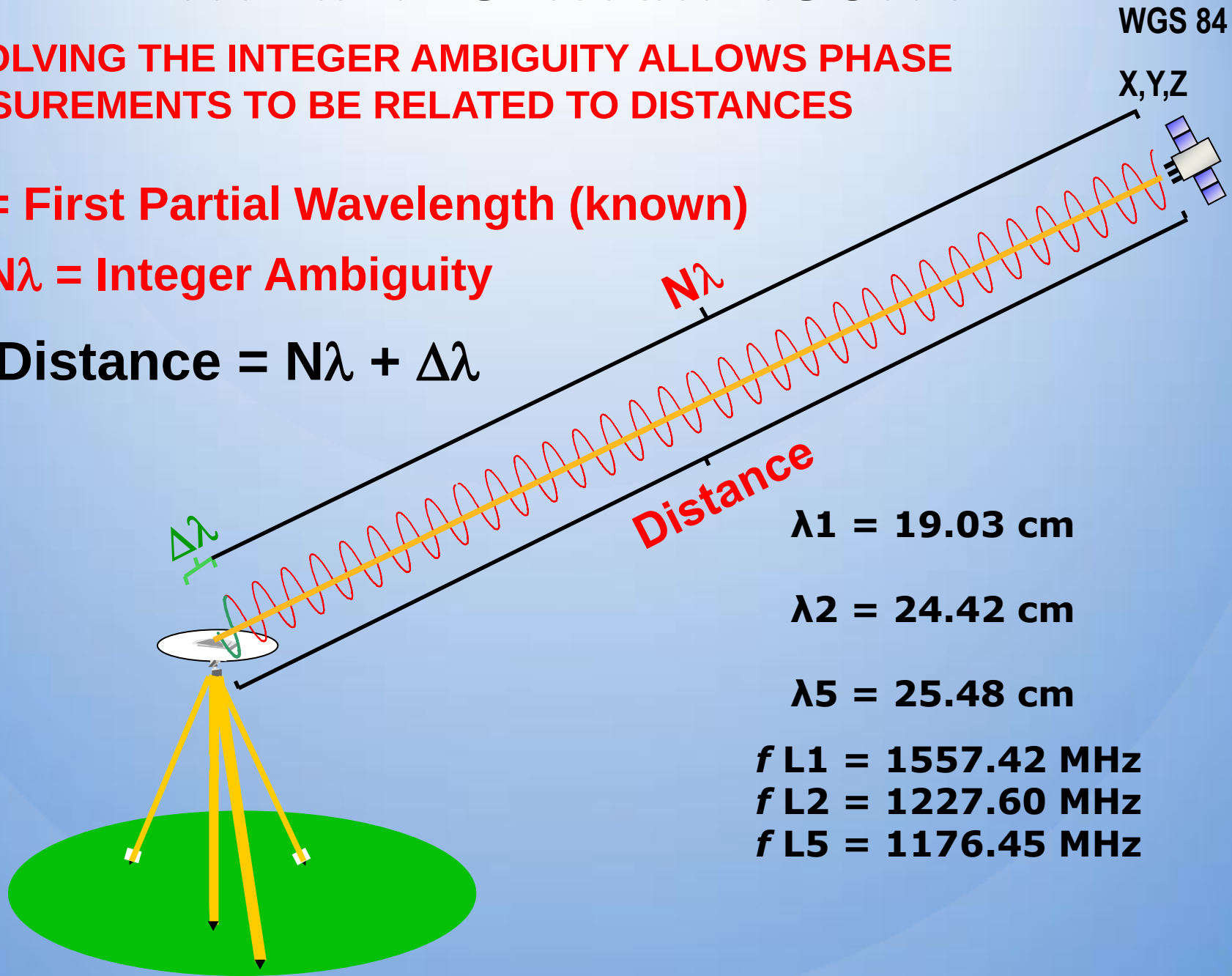
THE INTEGER AMBIGUITY

RESOLVING THE INTEGER AMBIGUITY ALLOWS PHASE MEASUREMENTS TO BE RELATED TO DISTANCES

$\Delta\lambda$ = First Partial Wavelength (known)

$N\lambda$ = Integer Ambiguity

Distance = $N\lambda + \Delta\lambda$



$\lambda_1 = 19.03 \text{ cm}$

$\lambda_2 = 24.42 \text{ cm}$

$\lambda_5 = 25.48 \text{ cm}$

$f_{L1} = 1557.42 \text{ MHz}$

$f_{L2} = 1227.60 \text{ MHz}$

$f_{L5} = 1176.45 \text{ MHz}$

THE AMBIGUITY SEARCH....

The ambiguity is an *integer* number (a multiple count 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).

Current GNSS technology allows very precise relative orthometric height precisions in a local project area with the same initialization.

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

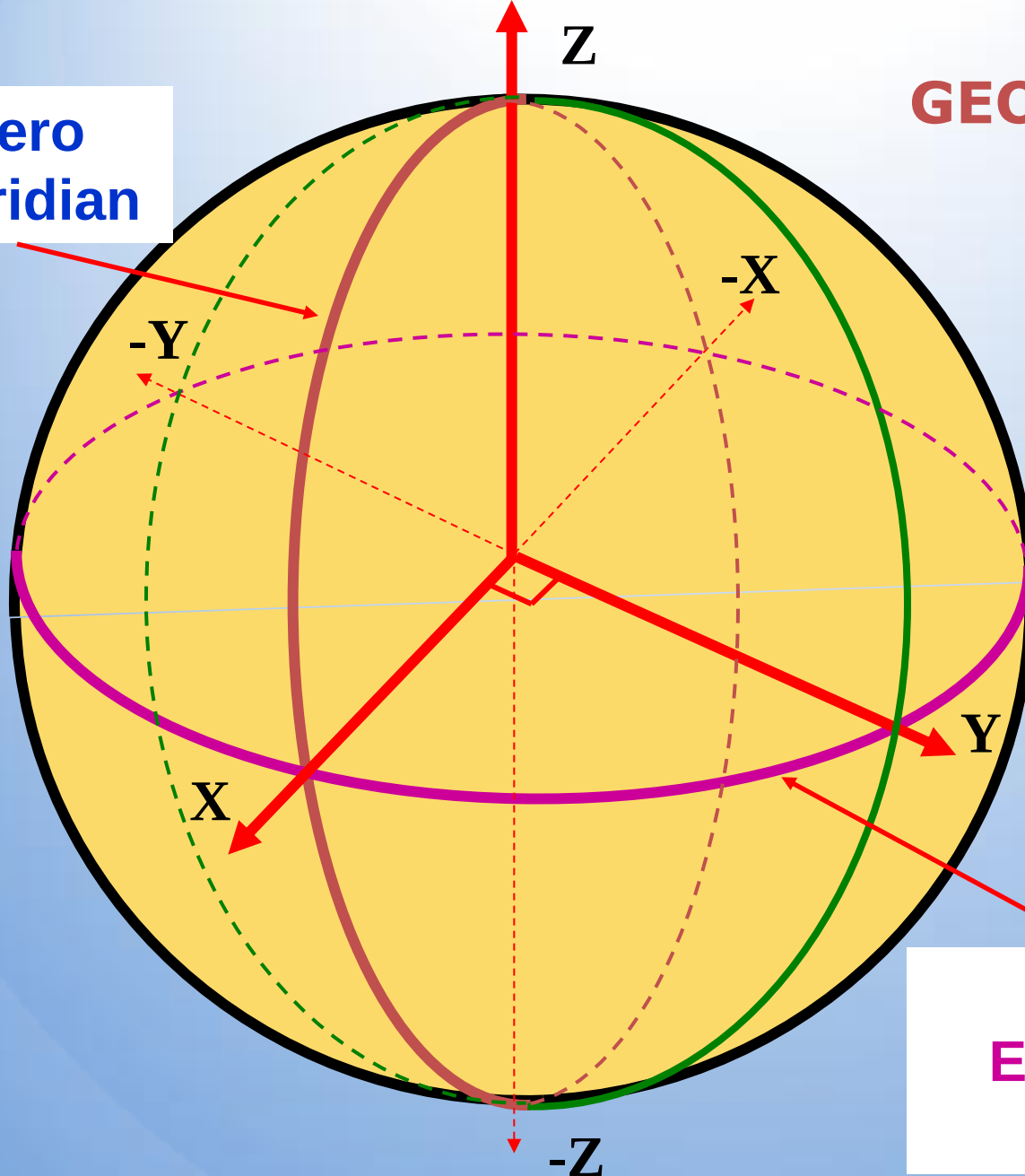
The determination of the cycle ambiguity integer is known as **ambiguity resolution (AR)**, and is generally not an easy task because of the presence of other biases and errors in the carrier phase measurement.

AR is only possible after all biases are eliminated or otherwise accounted for to better than one cycle (19 cm wavelength on L1)

HOW DOES RT CARRIER PHASE POSITIONING WORK?

- $\Delta X, Y, Z$ VECTOR FROM THE BASE COORDINATES, COMPUTED BY THE ROVER (REMEMBER “GIGO”)
- $\text{MULTILATERATION} = \text{TIME (SEC.)} \cdot C \text{ (SPEED OF LIGHT) (M/SEC.)} = \text{DISTANCE from satellites}$
- MUST RESOLVE THE AMBIGUOUS INTEGER NUMBER OF CARRIER PHASE CYCLES($\# \text{ cycles} \cdot \text{wave length} + \text{partial cycle} = \text{distance}$)
- 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
- MULTI-FREQUENCY COMBINATIONS AND DIFFERENCING CONTRIBUTE TO MITIGATING THE ERROR BUDGET

Zero
Meridian



GEODETIC DATUM=
• **SURFACE**
• **ORIENTATION**
• **SCALE**
• **ORIGIN**
+ **GRAVITY**

**AUTONOMOUS
GNSS
POSITIONS
ARE ECEF, XYZ
IN WGS 84
(~ITRF/IGS)**

**Mean
Equatorial
Plane**

GPS BASICS: LEARNING HOW GPS WORKS & HOW TO USE IT CORRECTLY



MSS 2014 PART 2: REAL-TIME POSITIONING OVERVIEW

ALAN DRAGOO
Prop LS.



BILL HENNING,
Prof LS.



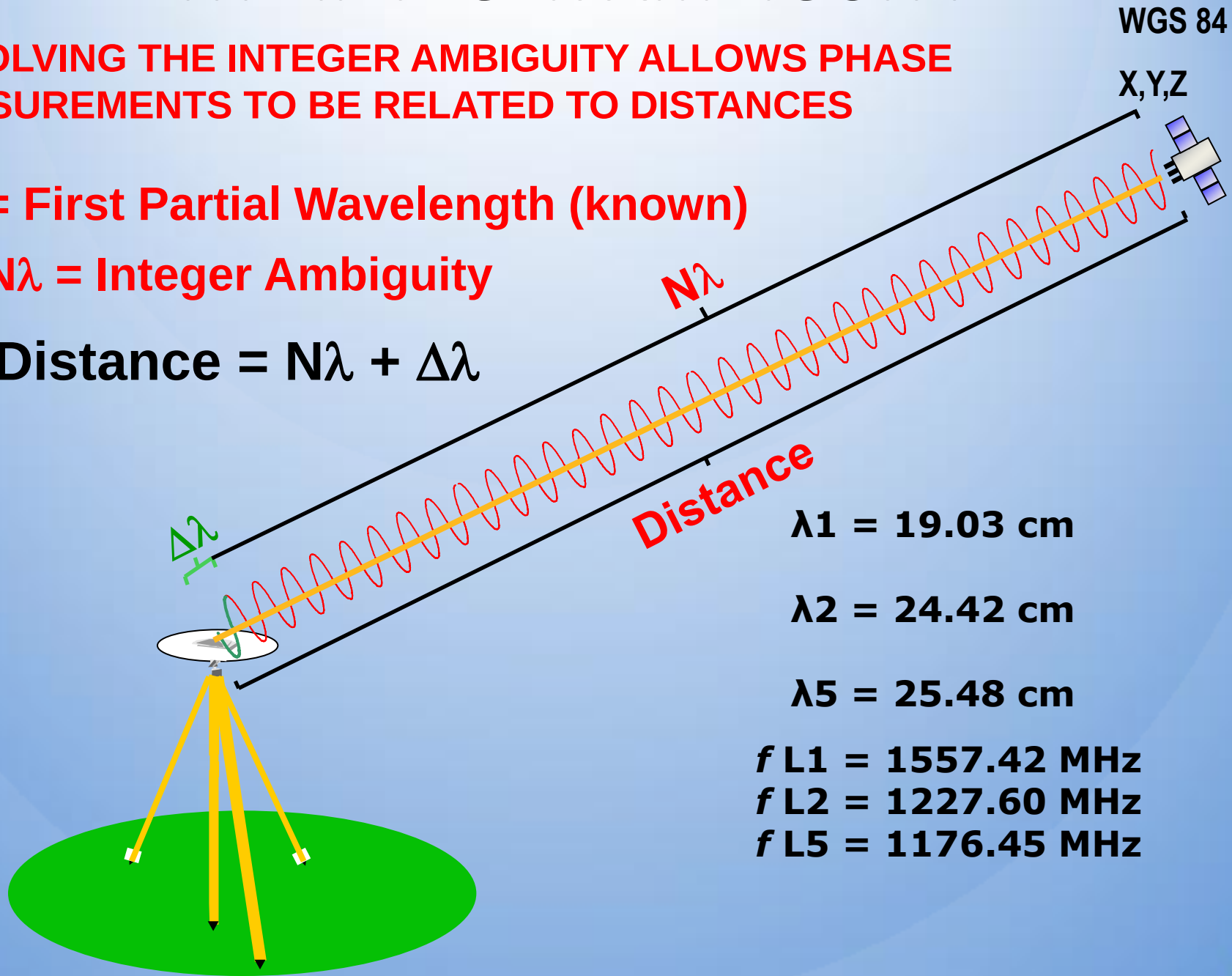
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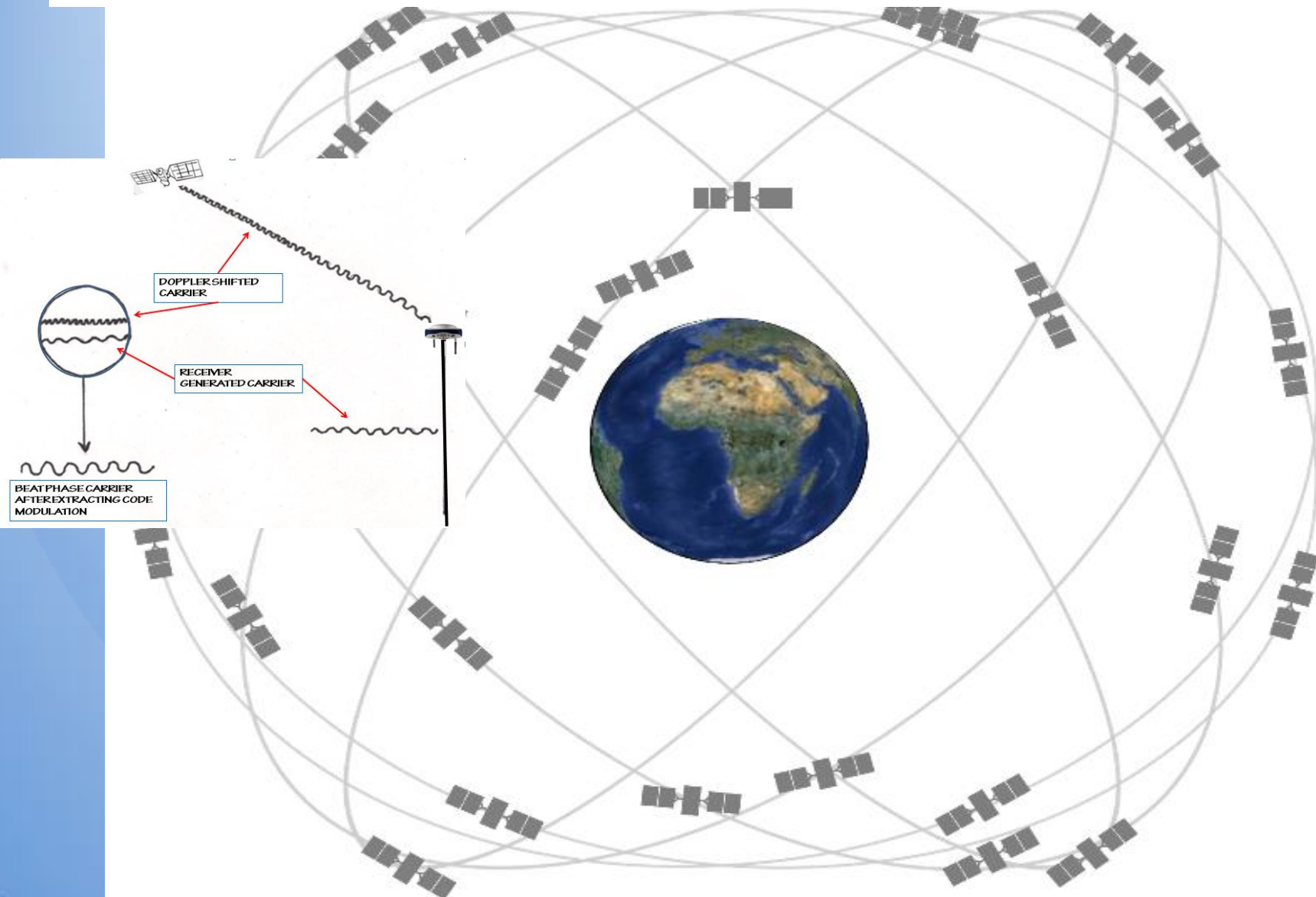
FLOAT vs. FIXED AMBIGUITY

SV	CYCLE COUNT ESTIMATIONS	
5	L1	103895488.223467
	L2	81893196.577789
9	L1	103895488.993467
	L2	81893196.767789
14	L1	103895488.115677
	L2	81893196.484329
15	L1	103895488.871167
	L2	81893196.993579
18	L1	103895488.223467
	L2	81893196.577789
21	L1	103895488.658907
	L2	81893196.475689
22	L1	103895488.559723
	L2	81893196.3999123

THE SOFTWARE MUST RESOLVE THESE DECIMAL SOLUTIONS TO AN INTEGER NUMBER FOR A CERTAIN TIME EPOCH AND FOR EACH FREQUENCY.



THE NATIVE CONDITION OF THE GNSS SIGNAL



OF
E
TO
ON,
BIT

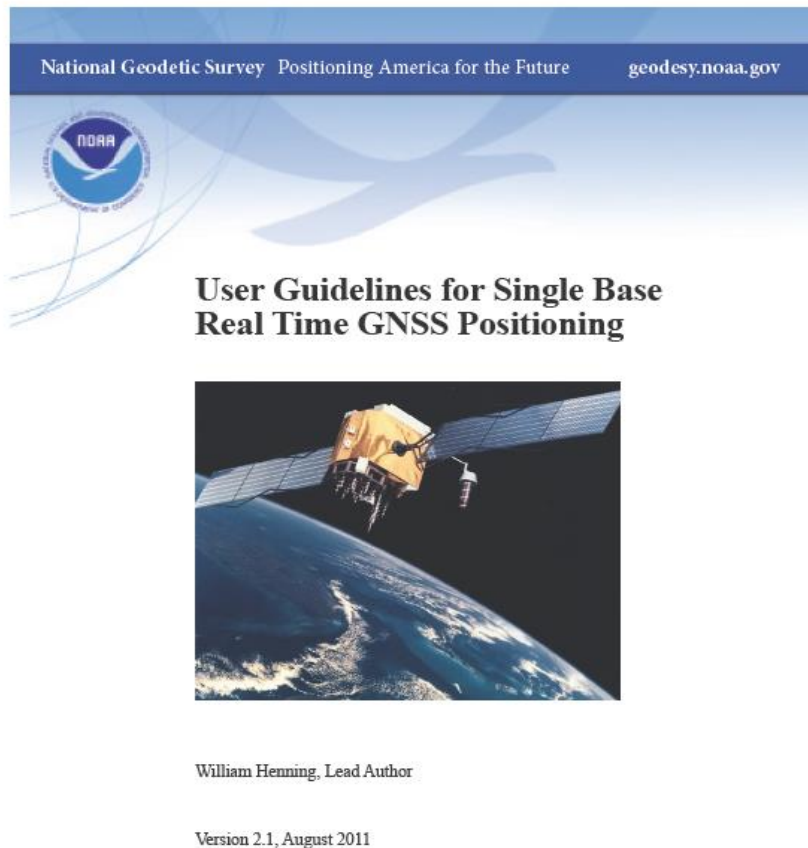
THE IMPORTANCE OF INTELLIGENT RT FIELD WORK

- *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/ITRF08/IGS08/NAD 83, & Local datums
- GPS, GLONASS, Galileo, Compass Constellations

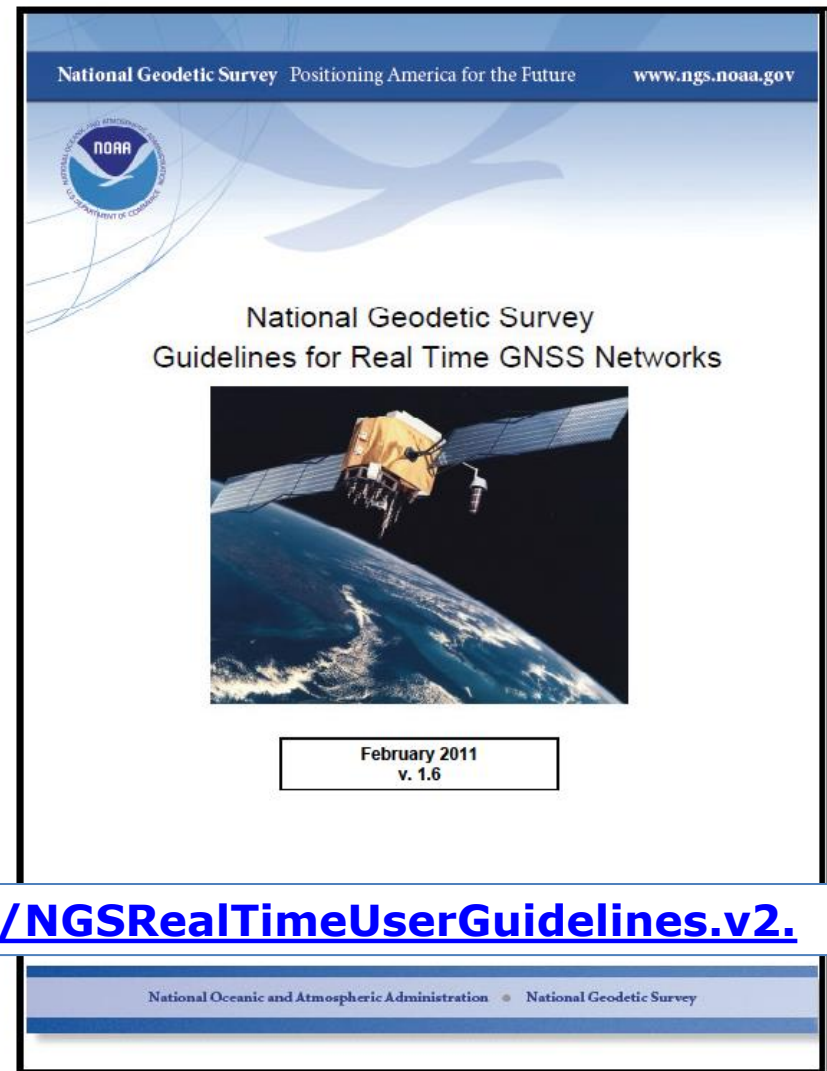
**THE CONTROL
IS AT THE POLE!**



REAL TIME GNSS GUIDELINES



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



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

RT FOR POSITIONING

ADVANTAGES:

- LESS TIME- SECONDS ON POINT
- LESS LABOR- NO POST PROCESSING, MINIMAL PERSONNEL
- LESS EQUIPMENT – ONLY ONE RT UNIT NECESSARY WITH RTN
- = LESS \$\$\$
- USER KNOWS POSITION HAS BEEN CAPTURED AT REQUIRED PRECISION
- “GOOD” *RELATIVE* PRECISION IN HOMOGENEOUS TERRAIN AND USING THE SAME INITIALIZATION
- **NEW GEOPOTENTIAL (AND GEOMETRIC) DATUM WILL BE ACCESSED THROUGH ACTIVE STATIONS**

DISADVANTAGES:

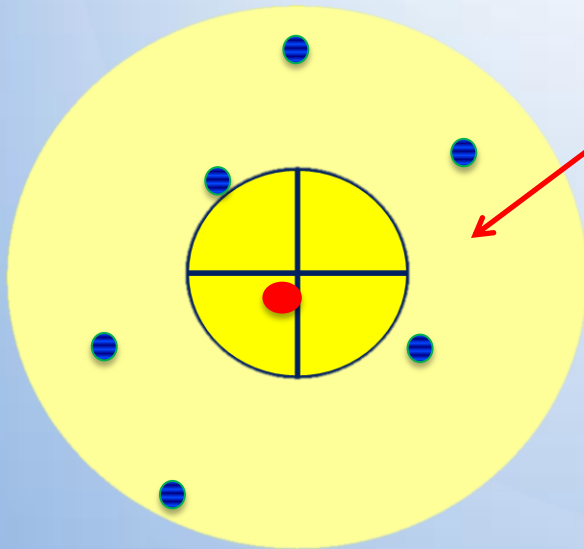
- LESS ACCURACY THAN LEVELING OR STATIC GNSS
- REQUIRES ADEQUATE USER KNOWLEDGE OF ALL EFFECTS ON RT GNSS POSITIONING

PRECISION VS. ACCURACY

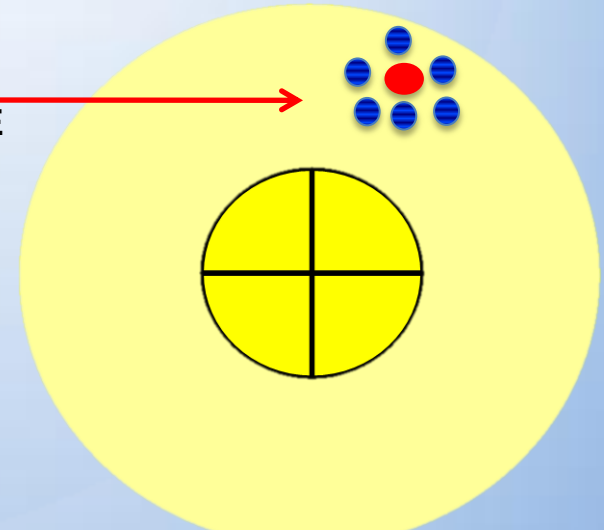
- “PRECISION” IS A COMPUTED STATISTICAL QUANTITY TO THE *SOURCE* OF THE MEASUREMENT - ALIGNMENT TO THE RTN OR PASSIVE MARK SHOWS PRECISION OF THE OBSERVATION (PER THE DATA COLLECTOR).
- “ACCURACY” IS A COMPUTED STATISTICAL QUANTITY TO THE REALIZATION OF THE DATUM TRUTH- ALIGNMENT OF THE RTN OR PASSIVE MARK TO THE NSRS SHOWS ACCURACY (PER ESTABLISHED METHODOLOGY)

PRECISION vs. ACCURACY

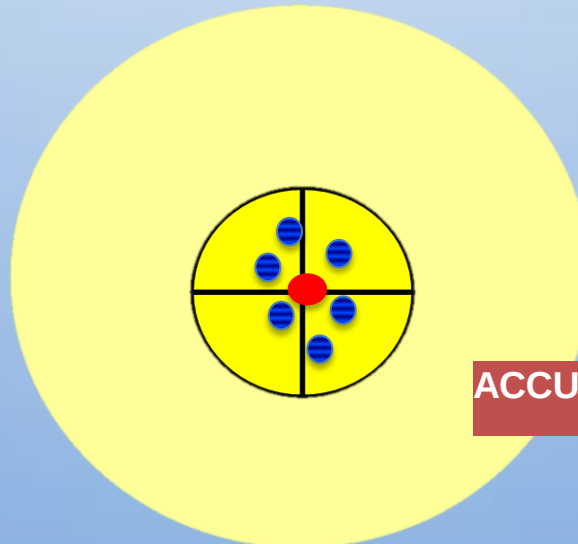
NOTE: SPREAD OF
SOLUTION
REFLECTED IN THE
"RMS". HIGH RMS
DOES NOT
NECESSARILY
MEAN A BAD
RESULT



ACCURATE – NOT PRECISE

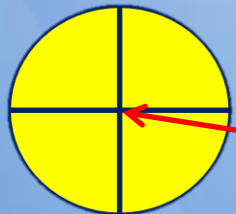


PRECISE – NOT ACCURATE



ACCURATE AND PRECISE

KEY



"TRUTH"



AVERAGE



ONE DATA POINT

THE THREE BASE STATION OPTIONS FOR REAL TIME DIFFERENTIAL POSITIONING (RT)

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

NETWORK SYSTEM
– PROVIDER
OPERATED. DATA
MODEMS, CELL
PHONES



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

“CONFIDENCE” IN YOUR POSITION INCREASES WITH:

The best of all single base worlds: 8 GPS satellites, GDOP 1.5, 2 km baseline, RMS $\leq$ 0.01 m, open sky, no weather elements, solid communication, no multipath

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

FOR RTN LOOK FOR:

GDOP $\leq$ 3 (or PDOP $\leq$ 2.5)

Number of GPS satellites $\geq$ 7

Time on point = 5 second record intervals for 1 minute

Position RMS $\leq$ 0.02 m horizontal, 0.04 vertical (ellipsoidal).

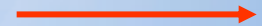
Redundancy $\geq$ 2 locations staggered by 3-4 hours. Redundant locations must differ no more than the desired point accuracy from the average of the coordinates as located.

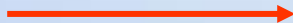
GNSS TO ANY DATUM IN YOUR DATA COLLECTOR

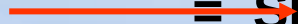


EXAMPLE: GPS TO SPC + ELEVATION:

GNSS ECEF X,Y,Z (GPS:WGS 84 & GLN:PZ90.02)



NAD 83 (ϕ, λ, h)  SPC N,E,h

+ HYBRID 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 THAT ARE CONSIDERED PROJECT “TRUTH”.

NGS SINGLE BASE GUIDELINES

- 4 CLASSES OF PRECISION (ACCURACY TO BASE)
- BEST METHODS FOR FIELD DATA COLLECTION
- BACKGROUND INFO. FOR RTK
- RTK GLOSSARY
- SUMMARY CHAPTER
- APPENDICES (INCLUDING LDP INFO.)

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

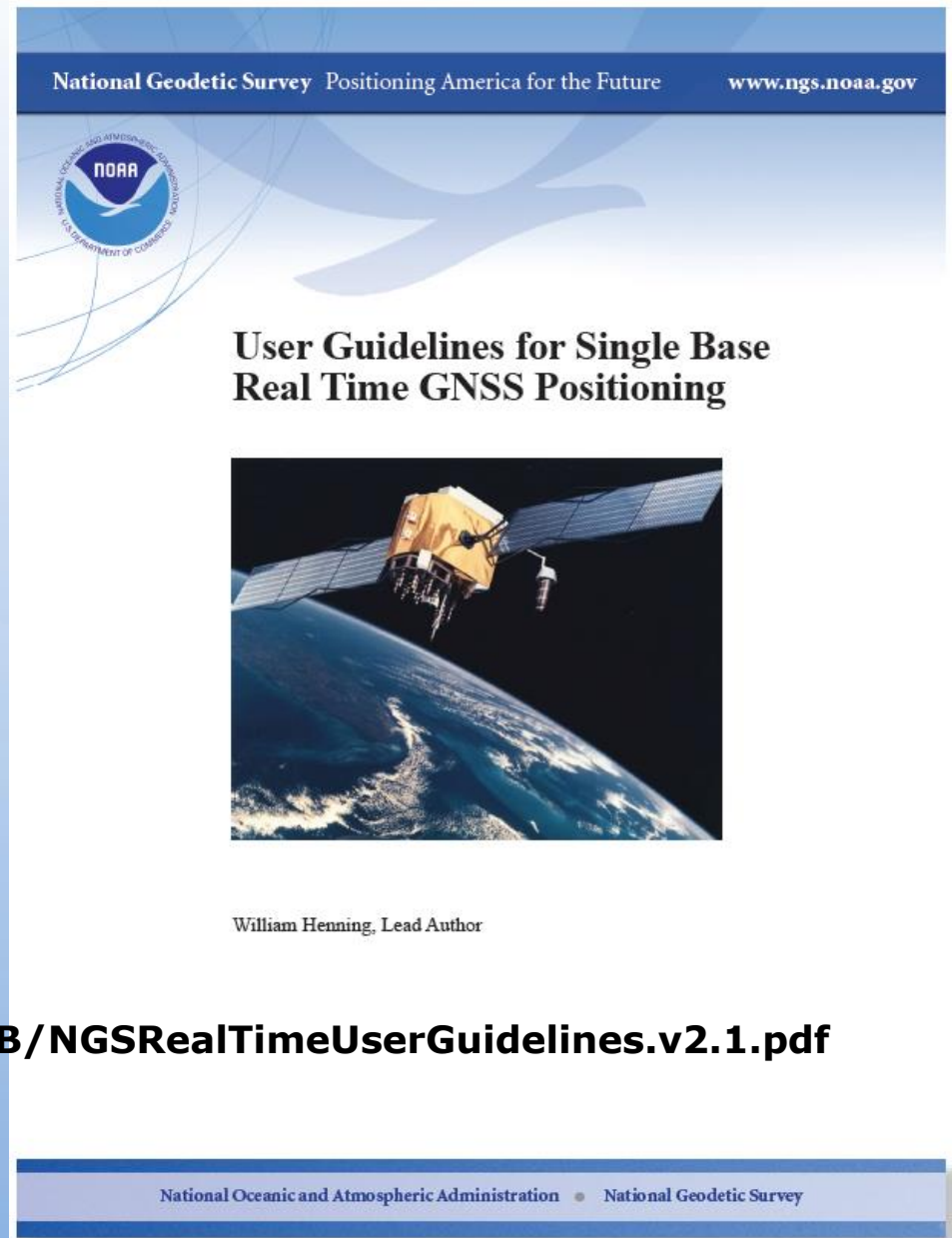


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RT USER GUIDELINES

SINGLE BASE 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 PHOTOPPOINTS UTILITY STAKE OUT	TOPOGRAPHY CROSS SECTIONS AGRICULTURE ROAD GRADING SITE GRADING	SITE GRADING WETLANDS GIS POPULATION MAPPING ENVIRONMENTAL

*** WITH 2 OR MORE BASES, TRY TO USE THOSE ON BOTH SIDES OF THE PROJECT AREA TO “STRETCH” THE GEOID MODEL**

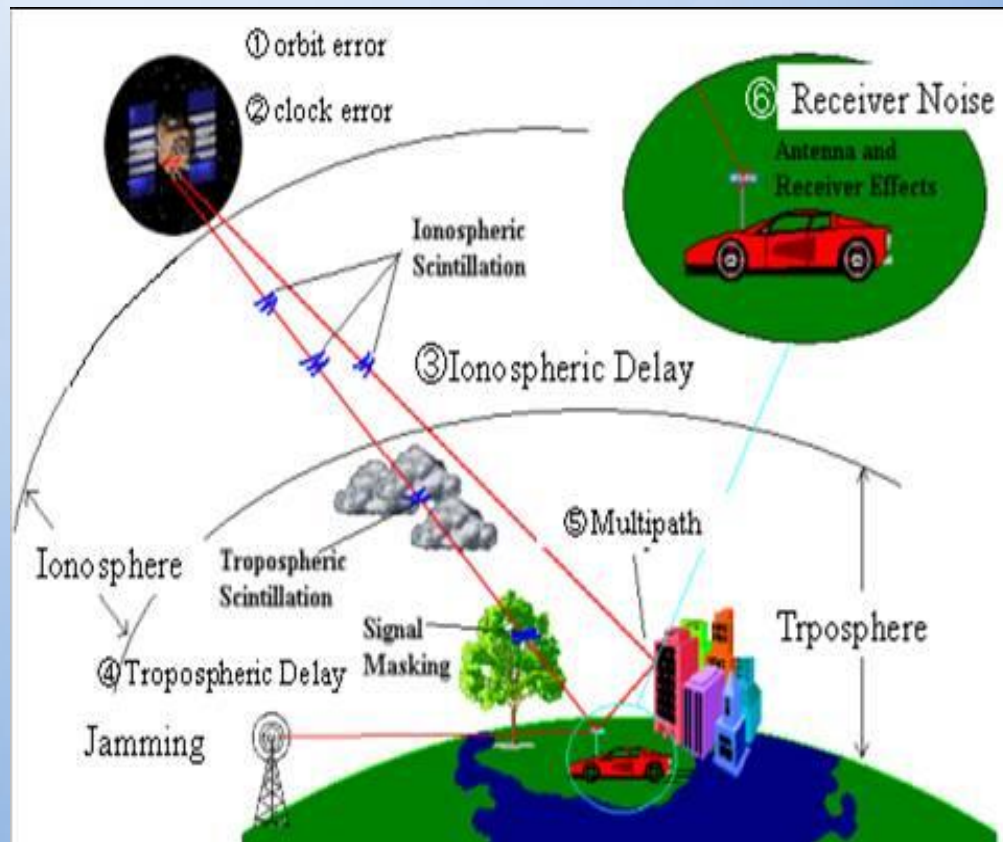
SOME SOURCES OF ERRORS & EFFECTS ON THE GNSS SIGNALS

- **IONOSPHERE : WATCH SPACE WEATHER**
- **TROPOSPHERE**
- **ORBITS**
- **PPM**
- **PRECISION VS. ACCURACY**
- **DILUTION OF PRECISION**
- **GLONASS INITIALIZATION**
- **RTN DATUMS AND/OR COORDINATES**

UNDIFFERENCED PHASE OBSERVABLE (CYCLES)

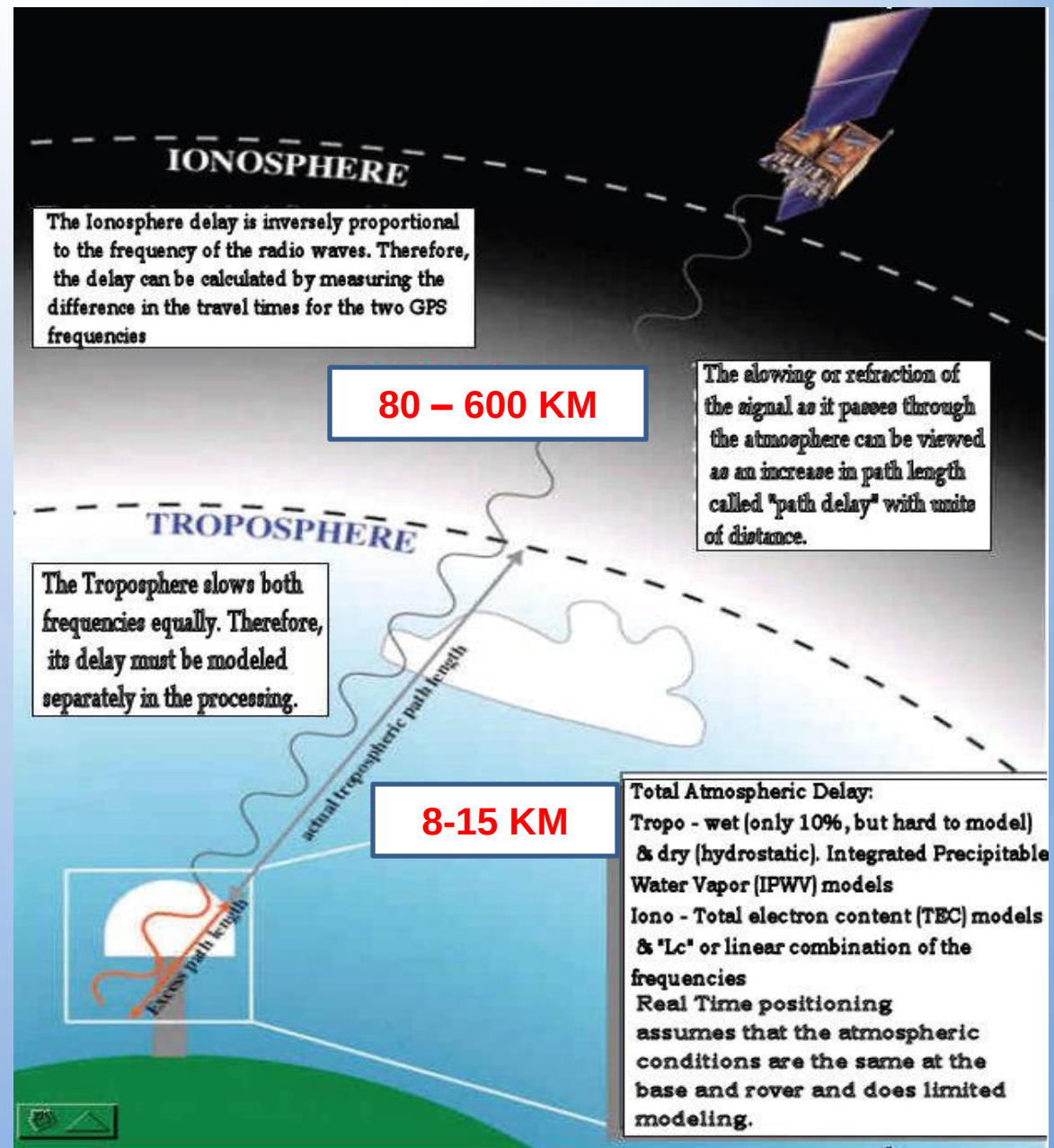
$$\varphi_k^p(t) = \frac{f}{c} \rho_k^p(t) - f dt_k(t) + f dt^p(t) + N_k^p - I_{k,\varphi}^p(t) + \frac{f}{c} T_{k,\varphi}^p(t) + d_{k,\varphi}(t) + d_{k,\varphi}^p(t) + d_\varphi^p(t) + \varepsilon_\varphi$$

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
UNCORRELATED ERROR	5.15 m (square root of sum of errors squared)



IONO & TROPO LAYERS AND THEIR EFFECT ON THE GNSS SIGNAL

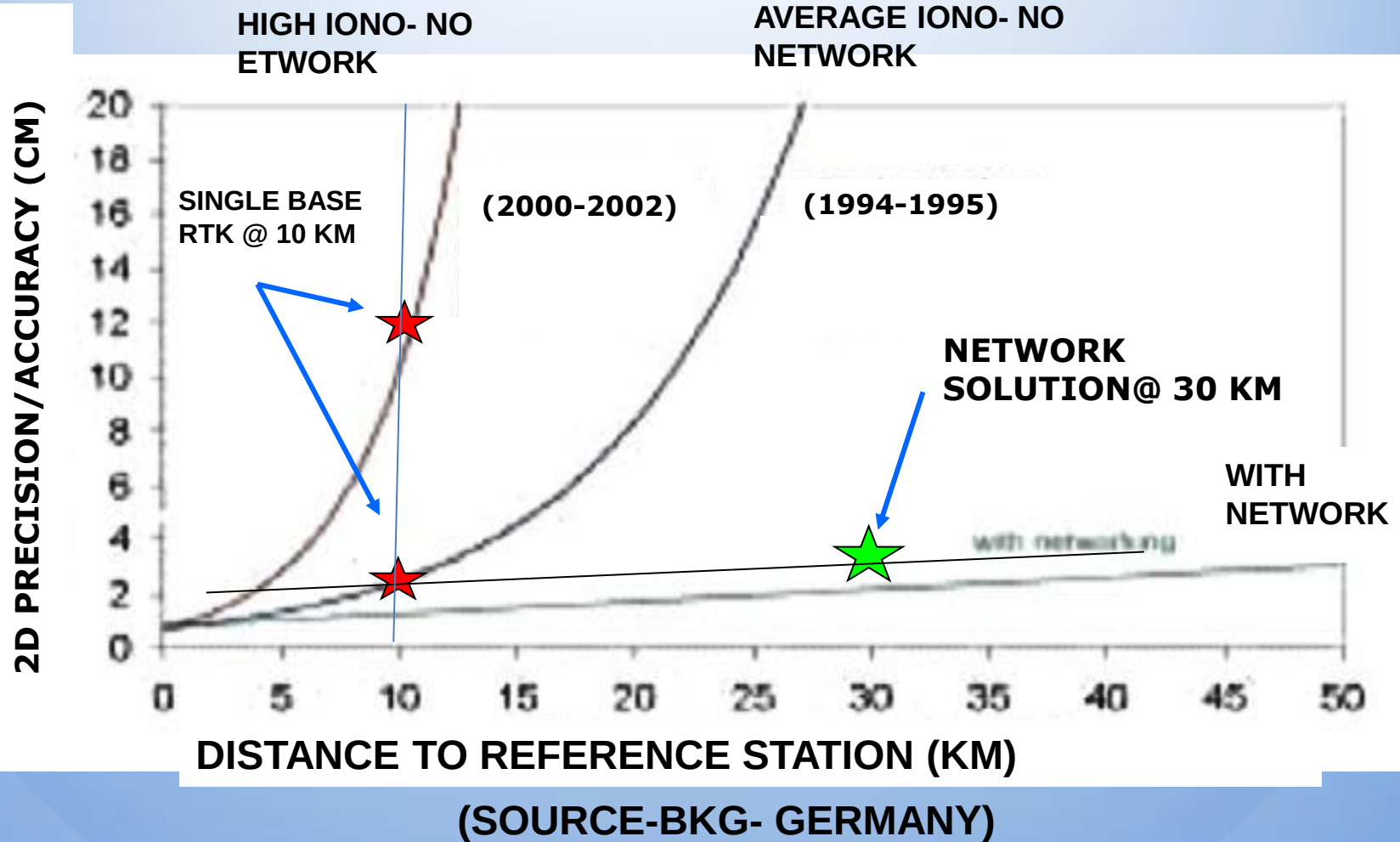
“Part(s) per million” (PPM) error



IONOSPHERIC DISTURBANCE CAN AFFECT OUR RT WORK IN (AT LEAST) THREE WAYS:

- IT CAN KNOCK OUT RADIO OR INTERNET (CELL) COMMUNICATION FOR 10'S OF MINUTES OR EVEN HOURS
- IT CAN “CHARGE” THE SATELLITES AND DEGRADE THEIR SIGNAL OR DROP OUT COMMUNICATION AS WELL AS AFFECTING THEIR ORBITS
- IT CAN INTRODUCE A LOT OF NOISE INTO OUR RT SOLUTION, USUALLY EVIDENCED BY INCREASED RMS AND LOWERING PRECISIONS

IONOSPHERIC EFFECTS ON POSITIONING

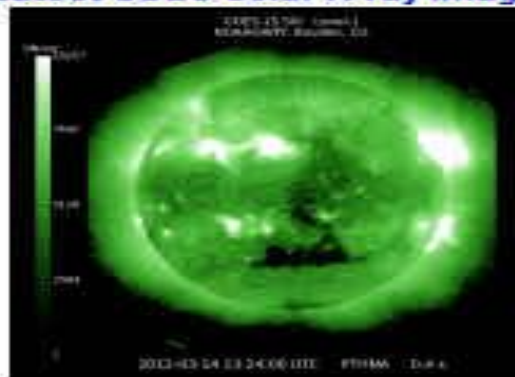


Current Space Weather Conditions

Satellite Displays -----

----- Popular Pages -----

[Latest GOES Solar X-ray Image](#)



NOAA Scales Activity

Range 1 (minor) to 5 (extreme)

Past 24 hours

Current

NOAA Scale

Geomagnetic Storms *

none

none

Solar Radiation Storms

52

51

Radio Blackouts

R2

none

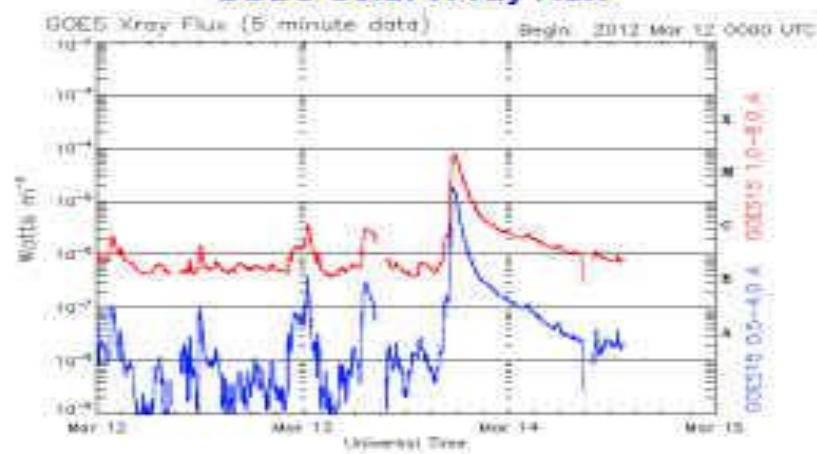
Satellite Environment Plot



Updated: 2012-Nov-16 13:36:07 (UTC)

NEW/NOTE-Editor, DO 1500

GOES Solar X-ray Flux



Updated: 2012-Mar-14 13:35:13 UTC

NDA#75WPC Boulder, CO USA

TROPOSPHERIC DELAY

The more air molecules, the slower the signal (dry delay)

High pressure, Low temperature

90% of total delay

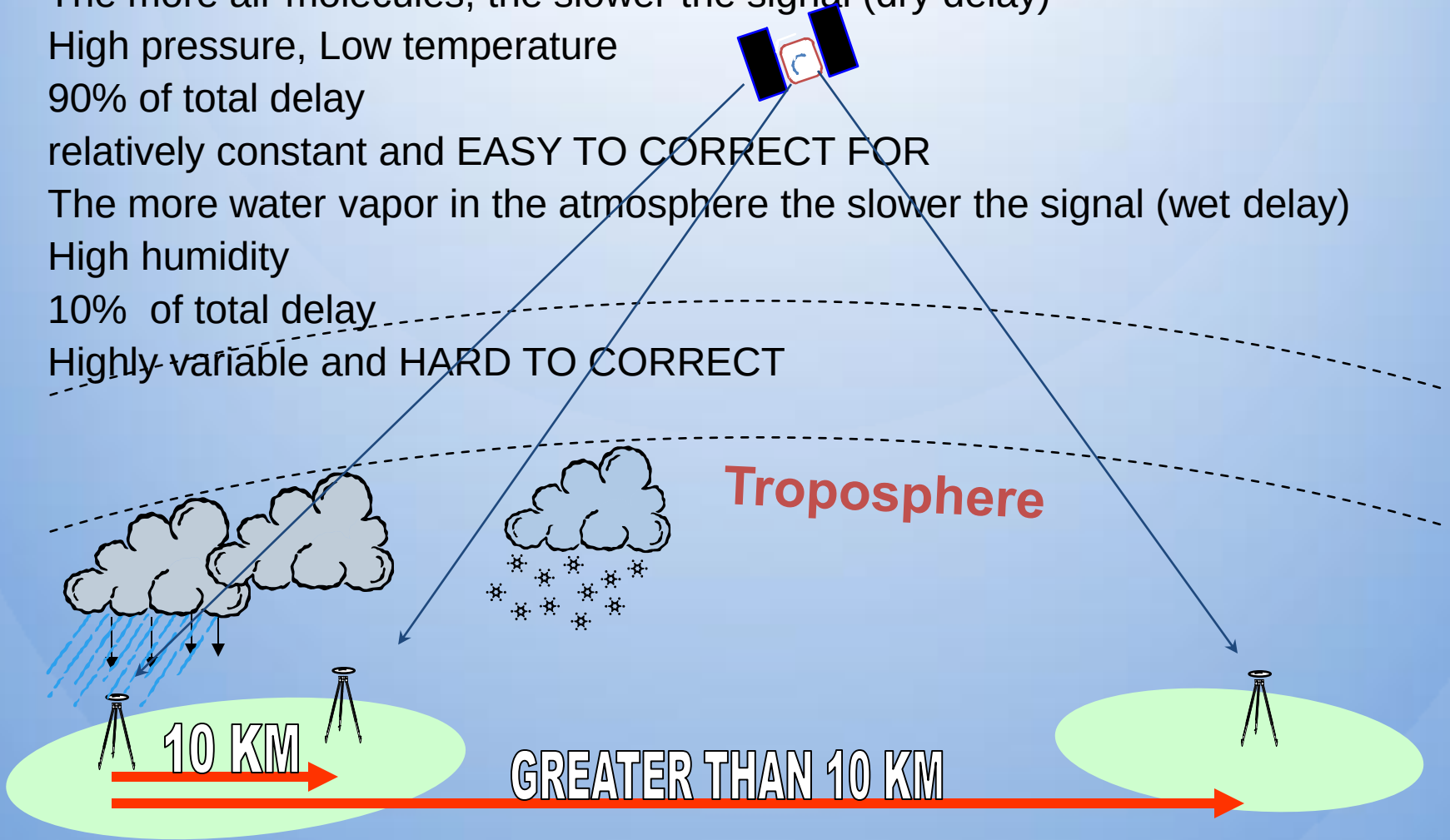
relatively constant and EASY TO CORRECT FOR

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



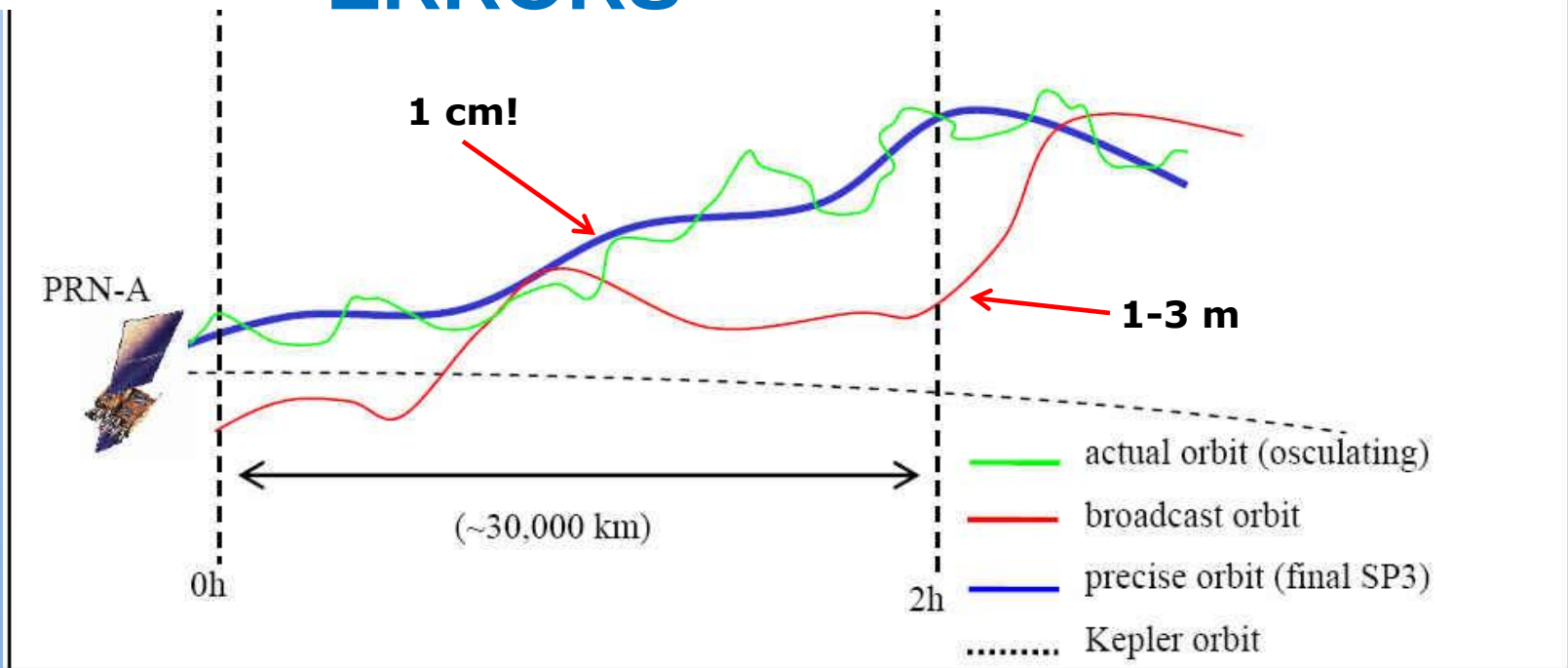
MITIGATING TROPOSPHERIC EFFECTS

- WITH SINGLE BASE REAL TIME POSITIONING, THE ROVER TRADITIONALLY USES “OBSERVATION SPACE” CORRECTIONS FROM THE BASE STATION. THE FURTHER ONE TRAVELS FROM THE BASE, THE MORE CHANCE THE TROPO CONDITIONS WILL DEVIATE BETWEEN THE TWO AND IS THUS REPRESENTED BY A PART(S) PER MILLION ERROR FACTOR AS SEEN IN THE GNSS MANUFACTURERS’ SPECS.

MITIGATING TROPOSPHERIC EFFECTS

- WITH A REAL TIME NETWORK, THE GEOMETRIC (NON-DISPERSIVE) EFFECTS OF ORBIT ERRORS AND TROPOSPHERIC DELAYS ARE MODELED BY THE NETWORK AND INTERPOLATED TO THE ROVERS POSITION. THUS THE FIRST ORDER PPM ERRORS ARE ELIMINATED.

ORBITAL ERRORS CONTRIBUTING TO PPM ERRORS



NOTE: RTK PRACTICE USES THE BROADCAST ORBITS, WHILE RTN MAY USE ULTRA RAPID, HALF-PREDICTED ORBITS

GRAPHIC:

Ahn, Yong Won (M.Sc. thesis), (2005), Analysis of NGS CORS Network for GPS RTK Performance Using External NOAA Tropospheric Corrections Integrated with a Multiple Reference Station Approach, *UCGE Report 20211*.



GPS Orbits

National Geodetic Survey

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GPS Orbit Data

IGS Orbit Availability

IGS Product Information

SP3 Conversion (sp3c → sp3a)

Ultra-rapid (iguWWWWD.sp3)
6-hour latency

The SP3-c format was developed to allow one to put GPS, GLONASS, and Galileo satellites all in the same file, and also to give standard deviations for the satellite XYZ coordinates and clock offset at each epoch

USED IN RTX/PPP

To enhance vertical accuracy use rapid orbits available in 24 hours

Broadcast Orbits ~ 1-3 m (real time)

Ultrarapid Orbits ~ 0.02- 0. 04 m (6 Hour Updates)

Rapid Orbits ~ 0.01 – 0.02 m (24 hours)

Precise Orbits ~ 0.005 – 0.01 m (10-14 days)

files named by GPS Week number and Day of Week

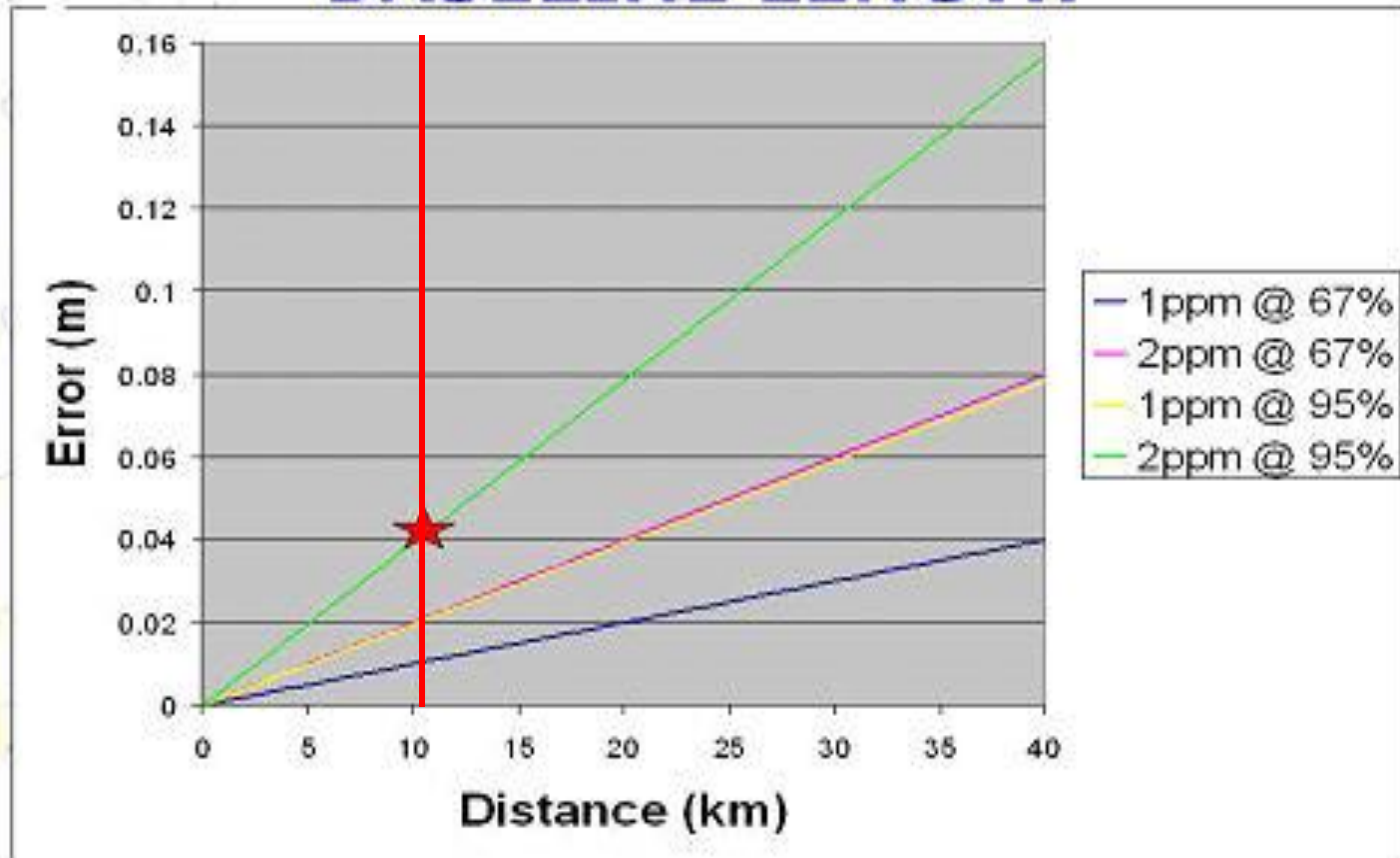
Website Owner: National Geodetic Survey - ORBITS / Last modified by Don Haw Feb 10 2012

NOS Home • NGS Employees • Privacy Policy • Disclaimer • USA.gov • Ready.gov • Site Map • Contact NGS Webmaster

http://www.ngs.noaa.gov/orbits/orbit_data.shtml

IONO, TROPO, ORBIT CONTRIBUTE TO PPM ERROR

RTK PPM ERROR VS. BASELINE LENGTH



REMEMBER GNSS EQUIPMENT MANUFACTURERS' SPECS!

SOME STATED PRECISIONS

TRIMBLE

POSITIONING PERFORMANCE¹

Code differential GNSS positioning

Horizontal..... 0.25 m + 1 ppm RMS

Vertical..... 0.50 m + 1 ppm RMS

SBAS differential positioning accuracy²..... typically <5 m 3DRMS

Static GNSS surveying

High-Precision Static

Horizontal..... 3 mm + 0.1 ppm RMS

Vertical..... 3.5 mm + 0.4 ppm RMS

Static and Fast Static

Horizontal..... 3 mm + 0.5 ppm RMS

Vertical..... 5 mm + 0.5 ppm RMS

Real Time Kinematic surveying³

Single Baseline <30 km

Horizontal..... 8 mm + 1 ppm RMS

Vertical..... 15 mm + 1 ppm RMS

Network RTK

Horizontal..... 8 mm + 0.5 ppm RMS

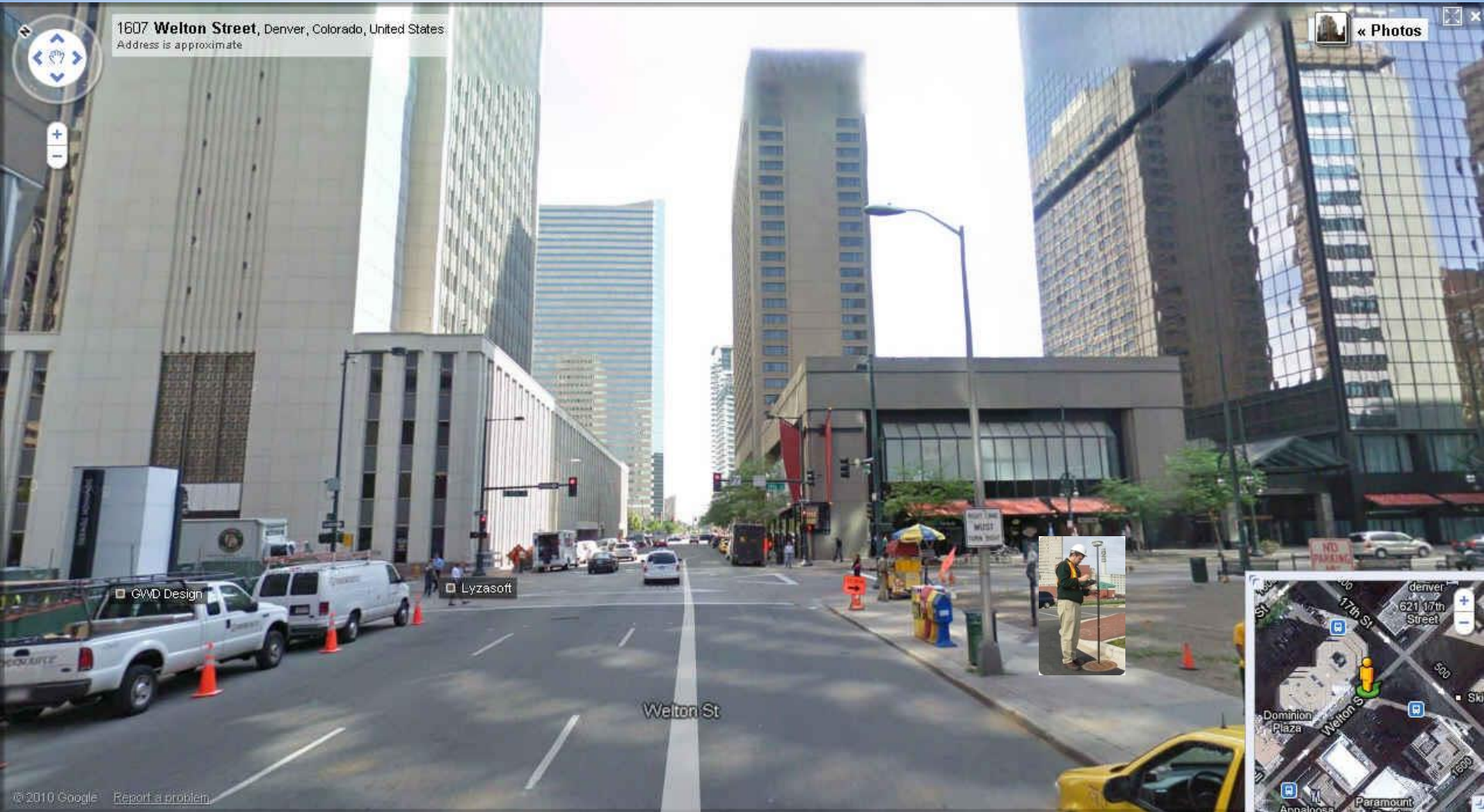
Vertical..... 15 mm + 0.5 ppm RMS

Initialization time⁴..... typically <8 seconds

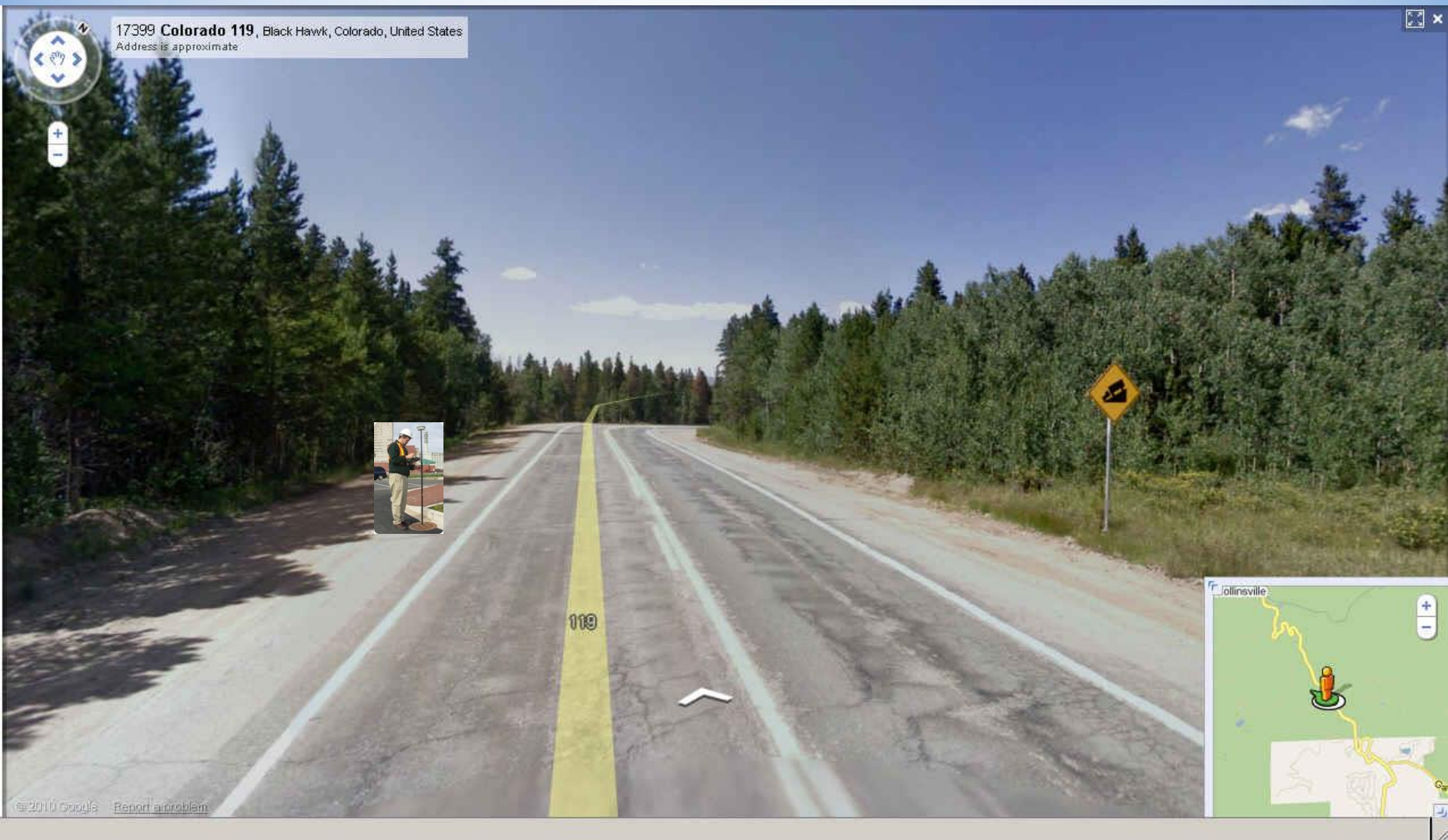
Initialization reliability⁴..... typically >99.9%

**TOPCON, ASHTECH, LEICA = 10 mm + 1PPM HORIZONTAL
20 mm + 1 PPM VERTICAL**

GNSS CAN HELP IN URBAN CANYONS

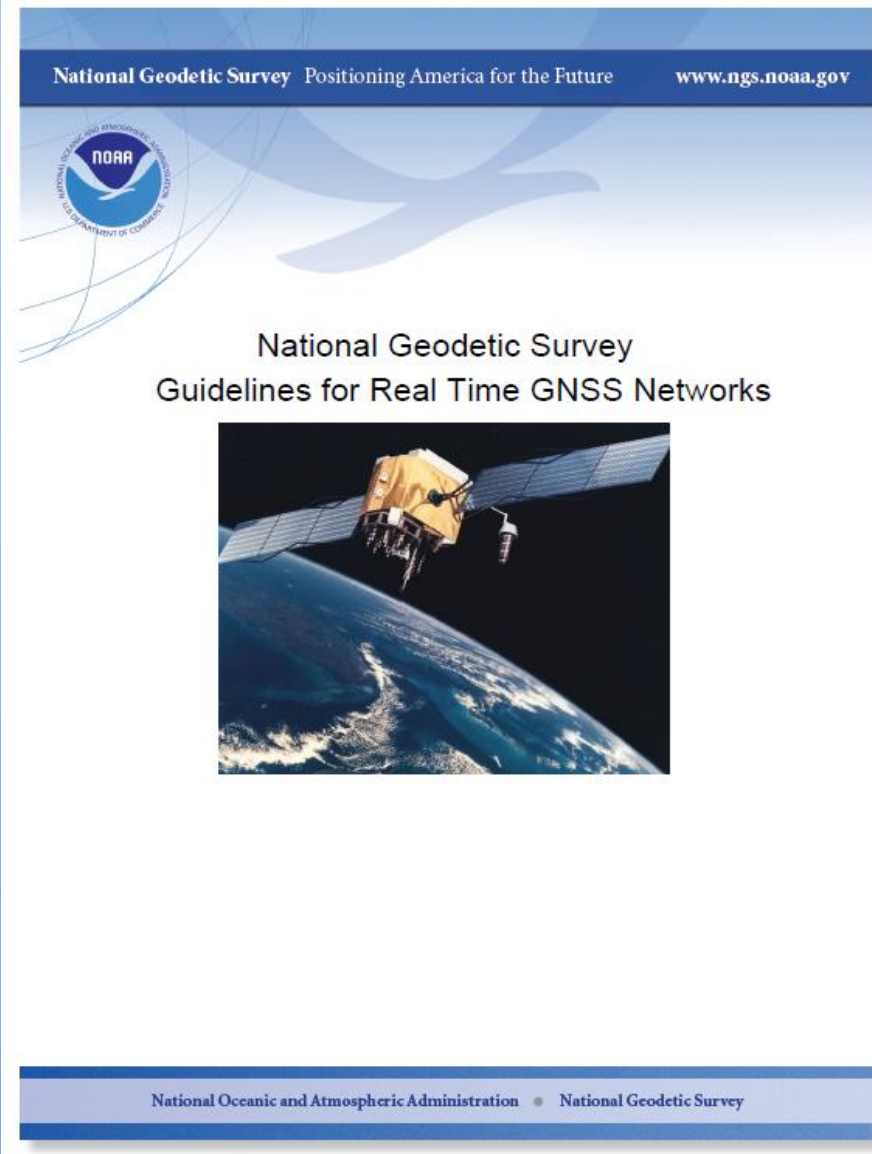


GNSS CAN HELP IN CORRIDOR SURVEYS



GNSS CAN HELP IN OBSTRUCTED AREAS





**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**

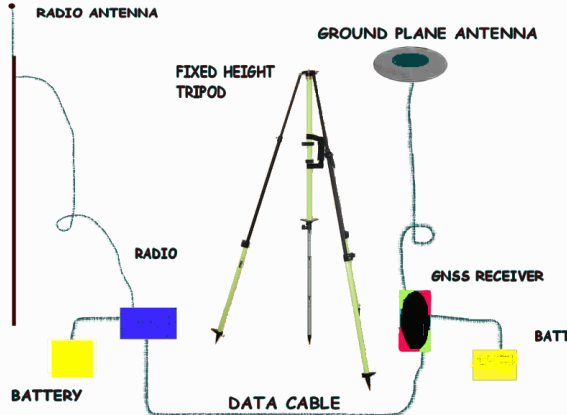
60+ CONTRIBUTORS:

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

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

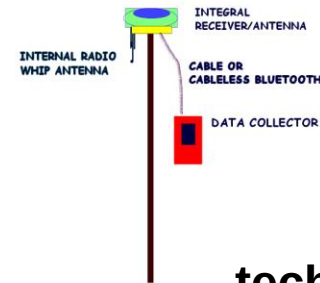
RTK VS. RTN

BASE STATION SET UP - UHF RADIO



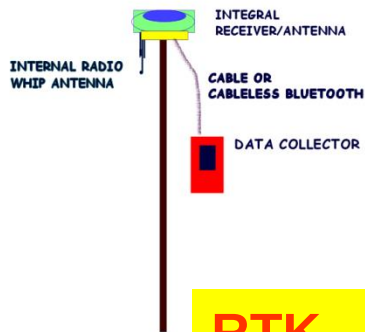
RTN

ROVER SET UP - INTERNAL RADIO



**Cell
technology**

ROVER SET UP - INTERNAL RADIO



RTK

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

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

NGS RTN GUIDELINES

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RTCM 3.X

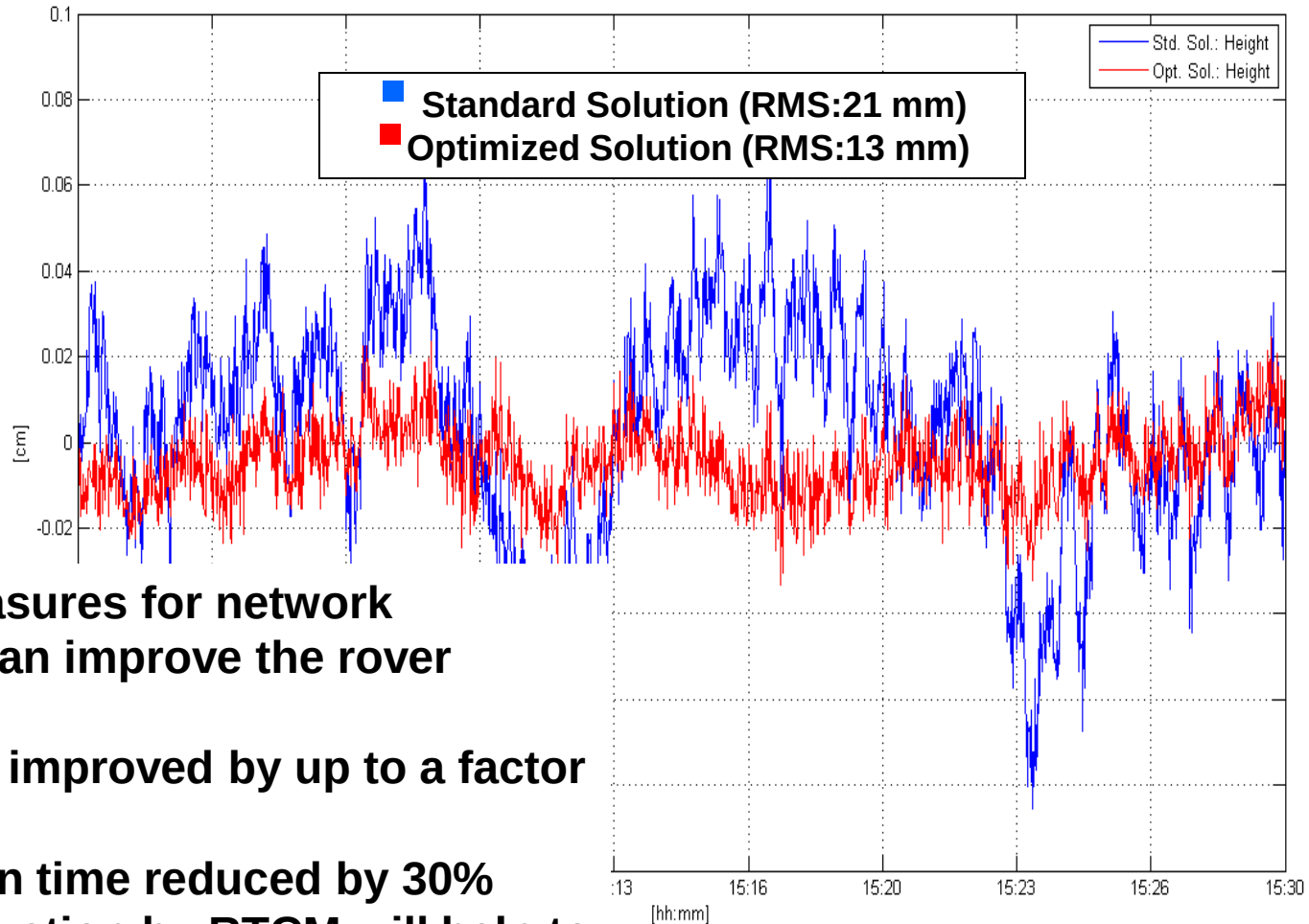
3.2 Message Type Summary

The message types shown in Table 3.2-1 support Real-Time Kinematic (RTK) individual and network broadcasts for GPS, GLONASS, .

Table 3.2-1. Message Type Table

Message Type	Message Name	No. of Bytes **	Notes
Message Type	Message Name	No. of Bytes **	Notes
1001	L1-Only		
1002	Extended	1015	GPS Ionospheric Correction Differences $9+3.75*N_s$ N_s = Number of Satellites
1003	L1&L2	1016	GPS Geometric Correction Differences $9+4.5*N_s$ N_s = Number of Satellites
1004	Extended	1017	GPS Combined Geometric and Ionospheric Correction Differences $9+6.625*N_s$ N_s = Number of Satellites
1005	Stationary	1018	RESERVED for Alternative Ionospheric Correction Difference Message
1006	Stationary with Antenna	1019	GPS Ephemerides 62 One message per satellite
1007	Antenna	1020	GLONASS Ephemerides 45 One message per satellite
1008	Antenna	1021	Helmert / Abridged Molodenski Transformation Parameters $51.5+N+M$ N = Number of characters in Source Name M = Number of characters in Target Name
1009	L1-Only	1022	Molodenski-Badekas Transformation Parameters $64.625+N+M$ N = Number of characters in Source Name M = Number of characters in Target Name
1010	Extended Observations	1023	Residuals, Ellipsoidal Grid Representation 72.25
1011	L1&L2	1024	Residuals, Plane Grid Representation 73.75
1012	Extended Observations	1025	Projection Parameters, Projection Types other than Lambert Conic Conformal (2 SP) and Oblique Mercator 24.5
1013	System	1026	Projection Parameters, Projection Type LCC2SP (Lambert Conic Conformal (2 SP)) 29.25
1014	Network	1027	Projection Parameters, Projection Type OM (Oblique Mercator) 32.25

POSITIONING ERROR COMPARISON – HEIGHT ERROR



- ✓ Quality measures for network corrections can improve the rover performance
- ✓ Positioning improved by up to a factor of 2
- ✓ Initialization time reduced by 30%
- ✓ A standardization by RTCM will help to get the method implemented in existing and new RTN networks

**RTCM Paper 014-2007-
SC104-462**

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?

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.**
- **RTK FROM A BASE ON SITE HELD AS “TRUTH” IS USUALLY SUPERIOR TO AN RTN.**

BEST METHODS FROM THE GUIDELINES: **THE SEVEN “C’s”**

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



NOAA SHIP “PISCES”

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

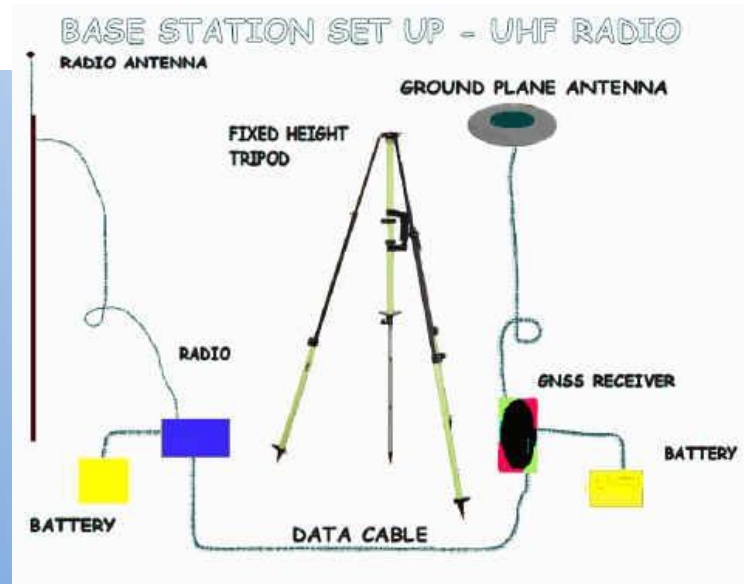
B = Both Single base and RTN

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?
- 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?

DUAL CONSTELLATION RT POSSIBILITIES:

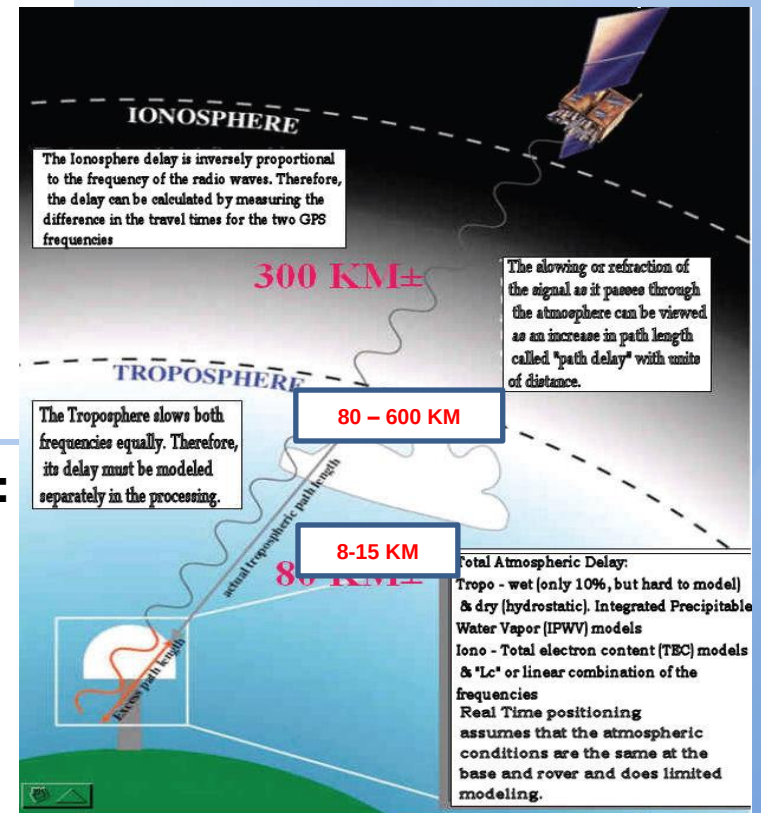
GPS $\geq$ 5, GLN = 0

GPS = 4, GLN = 2

GPS = 3, GLN = 3

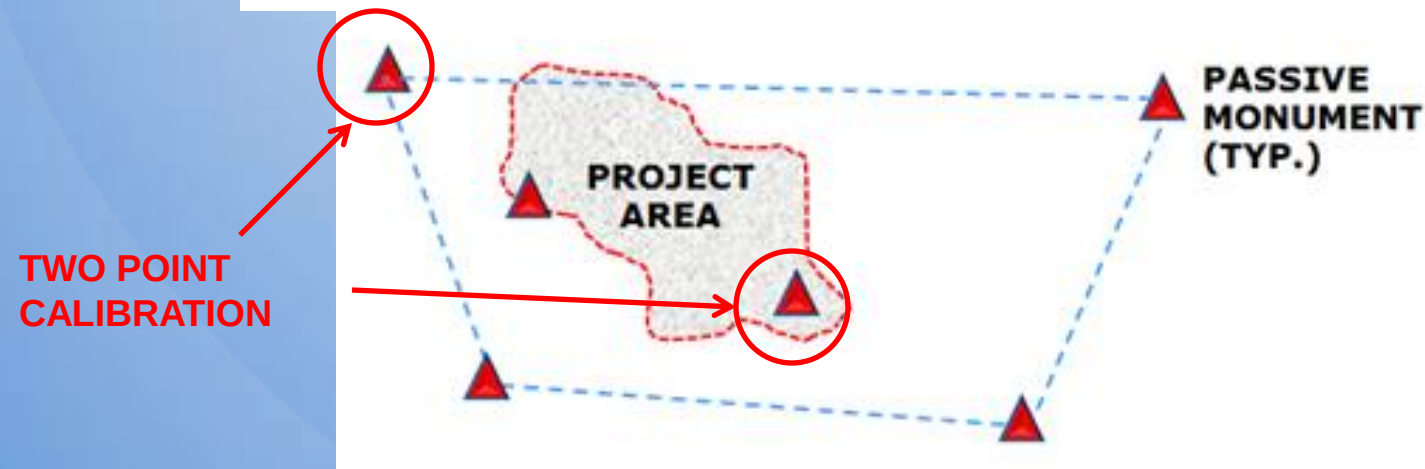
GPS = 2, GLN = 4

(Can't initialize with only GLN Sats.)



CONSTRAINTS (OR NOT)

- **B** ≥ 4 H & V, KNOWN & TRUSTED POINTS?
- **B** LOCALIZATION RESIDUALS-OUTLIERS?
- **B** DO ANY PASSIVE MARKS NEED TO BE HELD?
- **RT** BASE WITHIN CALIBRATION (QUALITY TIE TO NEAREST CALIBRATION POINT)?
- **B** SAME OFFICE & FIELD CALIBRATION USED?



CALIBRATIONS/VERTICAL LOCALIZATIONS

Residual Differences Between GPS A

Horizontal
Vertical
Three-dimensional

GPS point	
Point	
Latitude	39°09'42.25945"N
Longitude	76°39'26.89353"W
Height	

Point	
Latitude	39°09'42.25945"N
Longitude	76°39'26.89353"W
Height	

Point	
Latitude	39°09'42.25945"N
Longitude	76°39'26.89353"W
Height	

Point	HARWOODG
Latitude	39°11'59.51096"N
Longitude	76°44'16.00127"W
Height	83.693sft

GPS Site Calibration - Point List

Points:

Name	Value
- GPS Point	FRIENDG
- Latitude	39°09'42.25945"N
- Longitude	76°39'26.89353"W
- Height	-8.716sft
- Grid Point	FRIEND
- Northing	544668.360sft
- Easting	1409452.970sft
- Elevation	98.040sft
- Type	Horz and Vert
+ GPS Point	LR3G
+ Grid Point	LR3
- Type	Horz and Vert

Statistics

Horizontal adjustment scale factor:

0.99996488

Max vertical adjustment inclination:

33.317ppm

Max horizontal residual:

0.035sft

Max vertical residual:

0.006sft

OK

Cancel

Insert

Delete

vertical error	0.004sft
3D error	0.035sft

Point	HARWOODG
Latitude	39°11'59.51096"N
Longitude	76°44'16.00127"W
Height	83.693sft
Northing	558479.031sft
Easting	1386642.076sft
Elevation	189.562sft
Horizontal error	0.027sft
Vertical error	0.002sft
3D error	0.027sft

lean Square error	Point
0.009	GIS86G
0.001	LR3G
0.009	GIS86G

Control point	
Point	FRIEND
Northing	544668.360sft
Easting	1409452.970sft
Elevation	98.040sft
Type	Horz and Vert
Point quality	Control quality

Point	LR3
Northing	555685.700sft
Easting	1408208.310sft
Elevation	140.092sft
Type	Horz and Vert
Point quality	Control quality

Point	GIS86
Northing	566928.280sft
Easting	1397313.260sft
Elevation	57.130sft
Type	Horz and Vert
Point quality	Control quality

Point	HARWOOD
Northing	558479.010sft
Easting	1386642.060sft
Elevation	189.560sft
Type	Horz and Vert
Point quality	Control quality

LOCALIZING TO PROJECT CONTROL WITH GNSS

- ≥ 4 H & V, KNOWN & TRUSTED POINTS FORMING A RECTANGLE
- EVALUATE LOCALIZATION RESIDUALS-OUTLIERS
- DO ANY PASSIVE MARKS NEED TO BE HELD?
- ARE LEGACY PLANS BASED ON PASSIVE CONTROL ON SITE?
- RT BASE WITHIN A CALIBRATION SHOULD OBTAIN AQUALITY TIE TO NEAREST CALIBRATION POINT
- SAME OFFICE & FIELD CALIBRATION USED
- 2 POINT VERTICAL CALIBRATION IS POSSIBLE-IF YOU TRUST THE ELEVATIONS
- PLAN FOR THE FUTURE: USING REMOTE COORDINATES, UPDATING PASSIVE CONTROL

COORDINATES

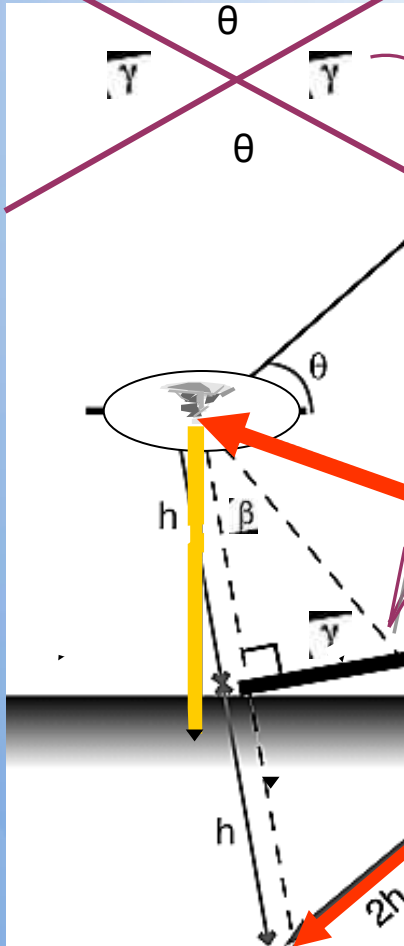
- **B** TRUSTED SOURCE?
- **B** WHAT DATUM/EPOCH ARE NEEDED?
- **RT** GIGO
- **B** ALWAYS CHECK KNOWN POINTS.
- ★ **B** PRECISION VS. ACCURACY
 - **B** GROUND/PROJECT VS. GRID/GEODETTIC
 - **B** GEOID MODEL QUALITY
 - **B** LOG METADATA

★ **AUTONOMOUS LOCAL BASE STATION POSITION CAN BE USED IF CORRECT COORDINATES ARE INTRODUCED IN THE PROJECT FIRMWARE/SOFTWARE LATER**

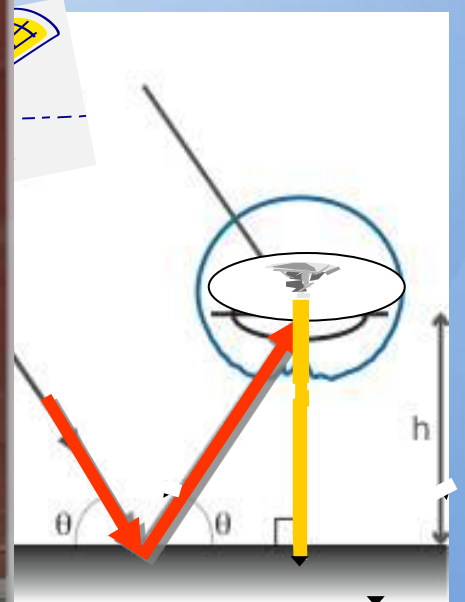
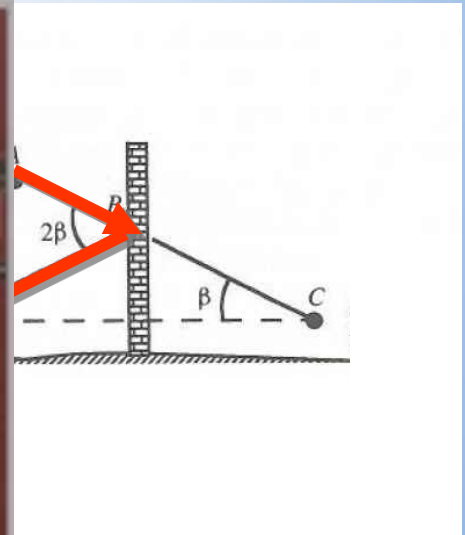
COLLECTION

- ★ B CHECK ON KNOWN POINTS AT START OF SESSION
 - B SET ELEVATION MASK
 - B ANTENNA TYPES & MODELING ENTERED OK? (USE ABSOLUTE MODEL IN ROVER UNLESS BASE STILL USES RELATIVE MODEL)
 - B SET COVARIANCE MATRICES ON (IF NECESSARY)
 - B RMS SHOWN IS TYPICALLY 68% CONFIDENCE
 - 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.

MULTIPATH



→ = EX



MULTIPATH = NOISE

SPECULAR(DISCRETE) & DIFFUSE

INSIDE GNSS

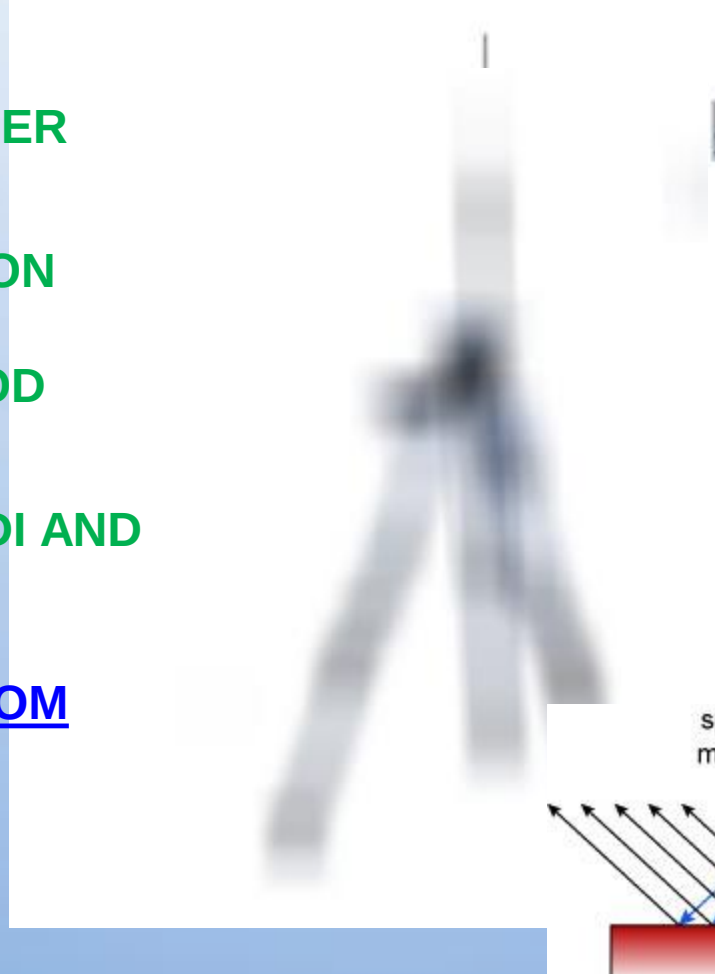
NOVEMBER-DECEMBER
2008

“MULTIATH-MITIGATION
TECHNIQUES USING
MAXIMUM-LIKELIHOOD
PRINCIPLE”

MOHAMED SAHMOUDI AND

RENE JR. LANDRY

WWW.INSIDEGNSS.COM



SOURCES:

TOWERS

BUILDINGS

WATER

VEHICLES

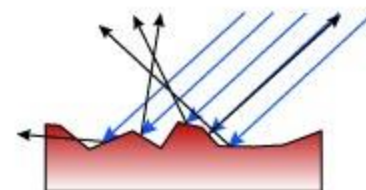
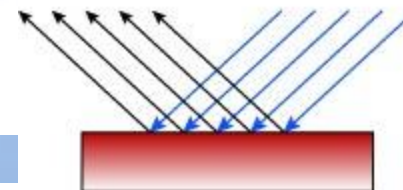
TREE CANOPY

STRUCTURES

**NEWER GNSS GEAR &
FIRMWARE ARE
BETTER!**

specular
multipath

diffuse
multipath



$$\varphi_k^p(t) = \frac{f}{c} \rho_k^p(t) - f \Delta t_k(t) + f \Delta t^p(t) + N_k^p - I_{k,p}^p(t) + \frac{f}{c} T_k^p(t) + d_{k,p}(t) + \boxed{d_{k,p}^p(t)} + d_p^p(t) + s_p$$

**BEWARE LONG
INITIALIZATION
TIMES-
MULTIPATH IS
SNEAKY
THIS LOCATION
WAS “FIXED” WITH
0.07’ – 0.10’
“BLUNDER
CHECKED”
PRECISIONS
DISPLAYED. IT WAS
0.65’ WRONG**



CONFIDENCE



CAN'T INITIALIZE? BAD CHECKS? PLENTY OF SATS? TRY:

▪ **TURN OFF GLONASS IF YOU HAVE ≥ 6 COMMON GPS SATS**

▪ **REININITIALIZE**

▪ **CHECK FOR “NOISY” SATS IN DATA COLLECTOR**

▪ **LOOK FOR MULTIPATH NEARBY**

ALSO-COMPARE GNSS POSITION TO GPS ONLY POSITION

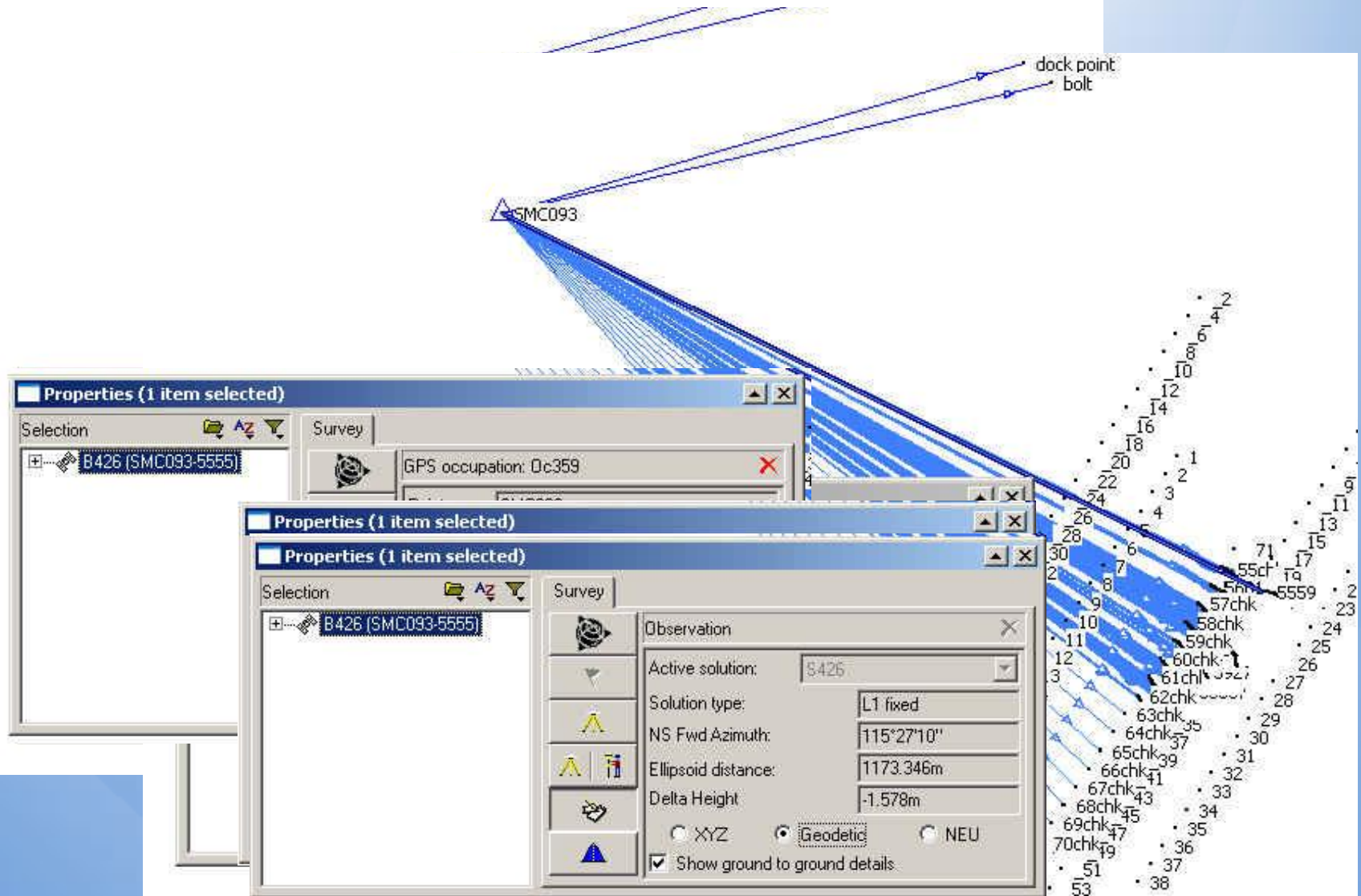
DIFFERENCE WITHIN NEEDS OF SURVEY

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

FURTHER WORK 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 PRACTITIONER 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 TABULAR CHECK LIST FORM)

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 USING RT FOR IMPORTANT POINTS

- **COMMUNICATIONS:** THE KEY TO SUCCESS, USE STRONG CONTINUOUS COMM CONNECTIONS FOR BEST PRECISION
- **CHECK SHOT:** FIRST BEFORE ANY NEW WORK, PERIODICALLY FOR BEST PRECISION WORK
- **REDUNDANCY:** FOR CONFIDENCE, ABSOLUTELY NEEDED FOR CONTROL POINTS
- **MULTIPATH:** AVOID UNSUITABLE CONDITIONS, OPEN SKY FOR CONTROL

GPS BASICS: LEARNING HOW GPS WORKS & HOW TO USE IT CORRECTLY



MSS 2014 PART 3: STATIC GNSS POSITIONING

ALAN DRAGOO
Prop LS.



BILL HENNING,
Prof LS.



SOME STATED PRECISIONS

POSITIONING PERFORMANCE¹

Code differential GNSS positioning

Horizontal.....	0.25 m + 1 ppm RMS
Vertical.....	0.50 m + 1 ppm RMS
SBAS differential positioning accuracy ²	typically <5 m 3DRMS

Static GNSS surveying

High-Precision Static

Horizontal.....	3 mm + 0.1 ppm RMS
Vertical.....	3.5 mm + 0.4 ppm RMS

Static and Fast Static

Horizontal.....	3 mm + 0.5 ppm RMS
Vertical.....	5 mm + 0.5 ppm RMS

TRIMBLE

Code and Phase Measurement Precision (irrespective whether AS off/on)

Carrier phase on L1	0.2mm rms
Carrier phase on L2	0.2mm rms
Code (pseudorange) on L1	2cm rms
Code (pseudorange) on L2	2cm rms

LEICA

Accuracy (rms) with real-time/RTK

RTK capability	Yes, standard
Kinematic (phase), moving mode after initialization	Horizontal: 10mm + 1ppm Vertical: 20mm + 1ppm
Code only	Typically 25cm

Accuracy (rms) in single receiver navigation mode

Navigation accuracy	5–10m rms for each coordinate
Degradation effect	Degradation possible due to SA

RTK baseline length

Standard 2500 metres. Option up to 5000 metres.

ACCURACY

RTK

H: 10 mm +
1 ppm

TOPCON

V: 15 mm + 1
ppm

Static/Fast Static

H: 3mm +
0.5ppm

V: 5mm +
0.5ppm

Real-Time Accuracy (RMS)^{2 3}

SBAS (WAAS/EGNOS/MSAS)

- Horizontal < 50 cm (1.64 ft)

Real-time DGPS position

Horizontal 25 cm (0.82 ft) + 1 ppm in
all conditions³

Real-time Kinematic Position (fine mode)

Horizontal 10 mm (0.033 ft) + 1.0 ppm
Vertical 20 mm (0.065 ft) + 1.0 ppm

Processing Accuracy (RMS)^{2 3}

Rapid Static

Horizontal 5 mm (0.016 ft) + 0.5 ppm
Vertical 10 mm (0.033 ft) + 0.5 ppm

Fast Static

Horizontal 3 mm (0.009 ft) + 0.5 ppm
Vertical 6 mm (0.019 ft) + 0.5 ppm

Processed Kinematic

Horizontal 10 mm (0.033 ft) + 1.0 ppm
Vertical 20 mm (0.065 ft) + 1.0 ppm

ASHTECH

HOW DOES CARRIER PHASE POSITIONING WORK?

- $\Delta X, Y, Z$ VECTOR FROM THE BASE COORDINATES, COMPUTED BY THE ROVER (REMEMBER “GIGO”)
- $\text{MULTILATERATION} = \text{TIME (SEC.)} \cdot C (\text{SPEED OF LIGHT}) (\text{M/SEC.}) = \text{DISTANCE from satellites}$
- MUST RESOLVE THE AMBIGUOUS INTEGER NUMBER OF CARRIER PHASE CYCLES($\# \text{ cycles} \cdot \text{wave length} + \text{partial cycle} = \text{distance}$)
- 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
- MULTI-FREQUENCY COMBINATIONS AND DIFFERENCING CONTRIBUTE TO MITIGATING THE ERROR BUDGET

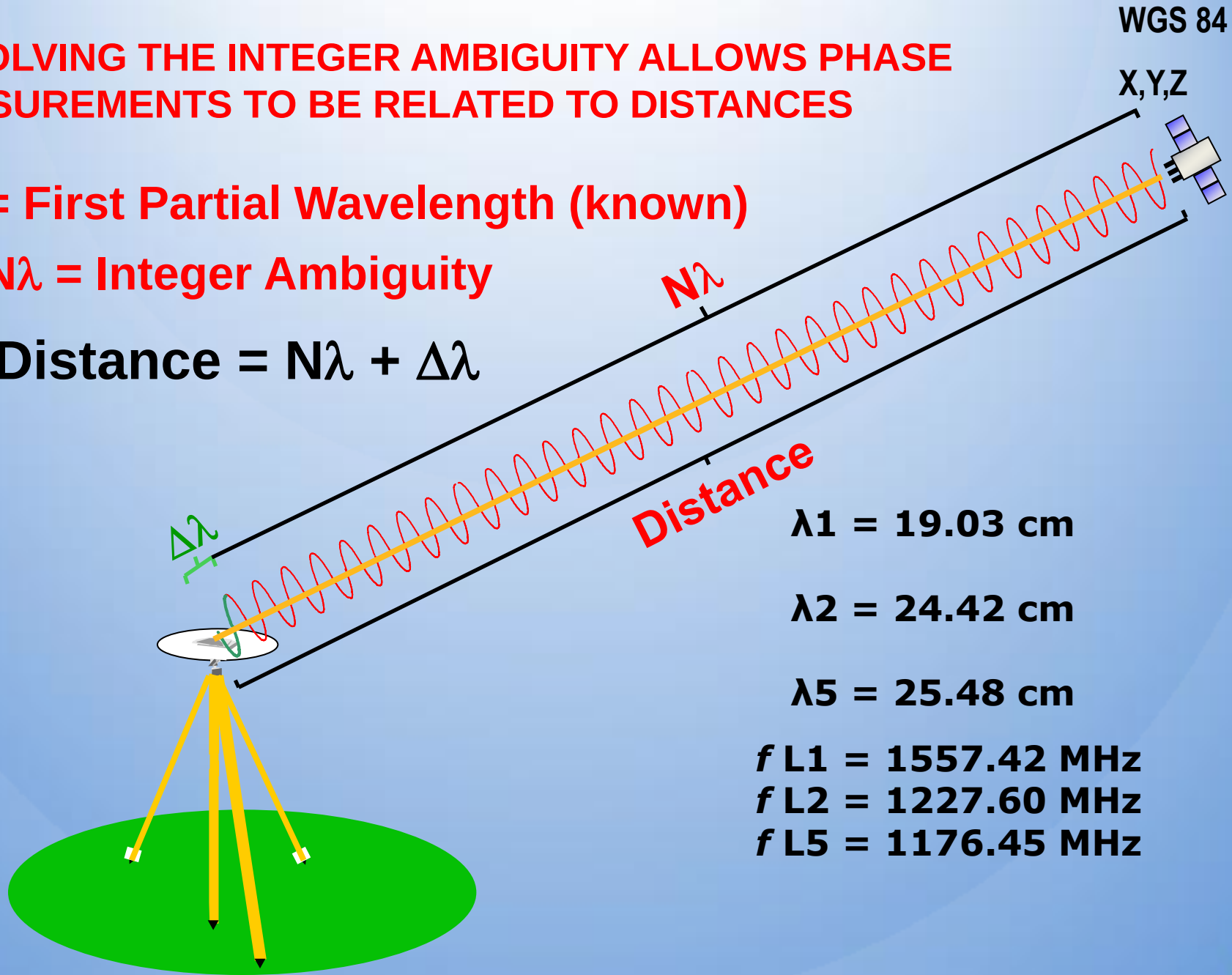
THE INTEGER AMBIGUITY

RESOLVING THE INTEGER AMBIGUITY ALLOWS PHASE MEASUREMENTS TO BE RELATED TO DISTANCES

$\Delta\lambda$ = First Partial Wavelength (known)

$N\lambda$ = Integer Ambiguity

$$\text{Distance} = N\lambda + \Delta\lambda$$



$$\lambda_1 = 19.03 \text{ cm}$$

$$\lambda_2 = 24.42 \text{ cm}$$

$$\lambda_5 = 25.48 \text{ cm}$$

$$f_{L1} = 1557.42 \text{ MHz}$$

$$f_{L2} = 1227.60 \text{ MHz}$$

$$f_{L5} = 1176.45 \text{ MHz}$$

THE AMBIGUITY SEARCH....

The ambiguity is an *integer* number (a multiple count 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).

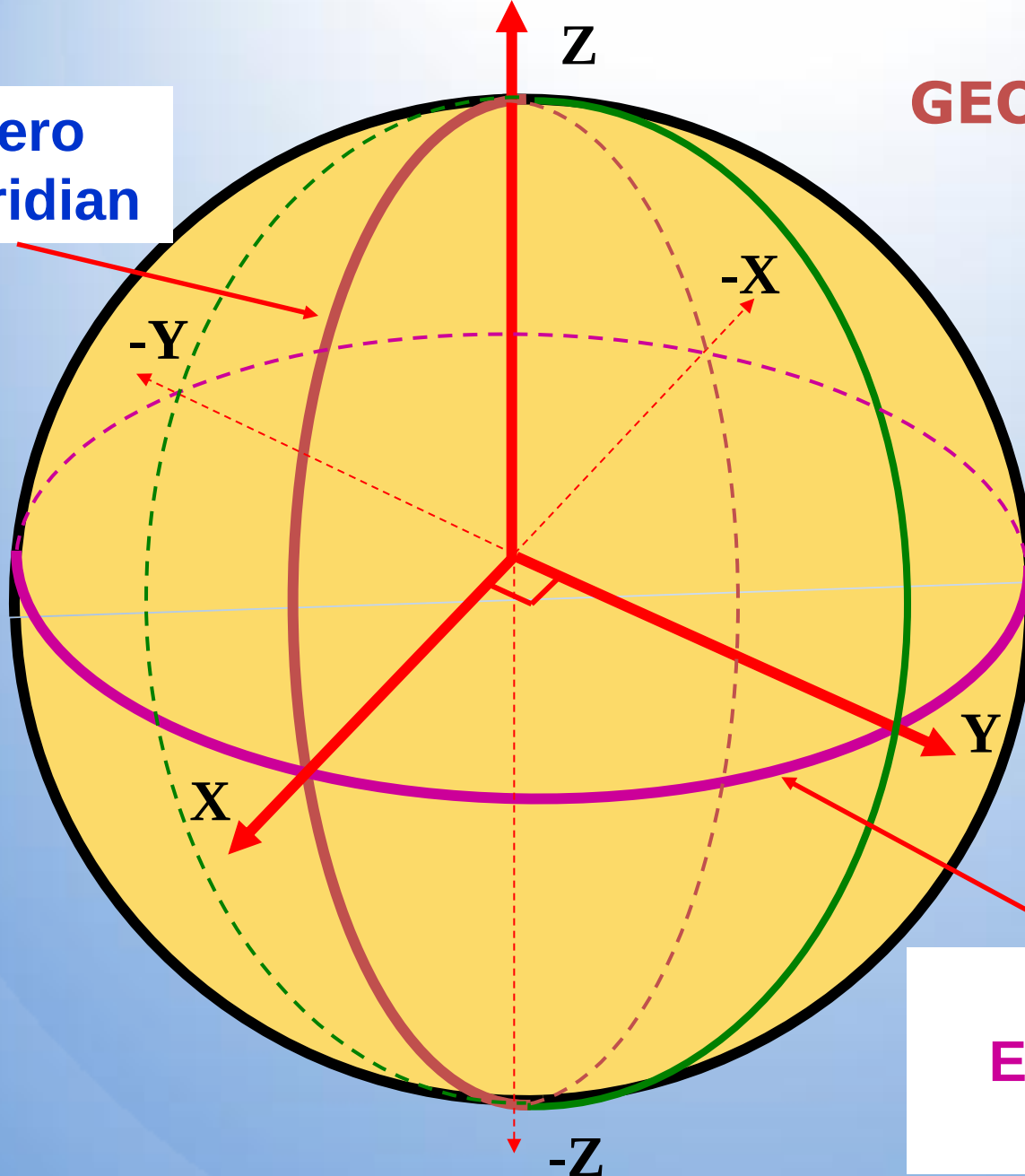
Current GNSS technology allows very precise relative orthometric height precisions in a local project area with the same initialization.

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 (AR)**, and is generally not an easy task because of the presence of other biases and errors in the carrier phase measurement.

AR is only possible after all biases are eliminated or otherwise accounted for to better than one cycle (19 cm wavelength on L1)

Zero
Meridian



GEODETIC DATUM=
• **SURFACE**
• **ORIENTATION**
• **SCALE**
• **ORIGIN**
+ **GRAVITY**

**AUTONOMOUS
GNSS
POSITIONS
ARE ECEF, XYZ
IN WGS 84
(~ITRF/IGS)**

**Mean
Equatorial
Plane**

POSITIONS FROM GNSS OBSERVATIONS

- STATIC POST PROCESSING- USING PASSIVE MARKS
- STATIC ACTIVE STATION POST PROCESSING (CORS DATA)
- STATIC NGS POST PROCESSING (OPUS)
- REAL TIME – YOUR BASE
- REAL TIME – NETWORK SUPPLIED
- AUTONOMOUS

WHAT GNSS METHOD SHOULD I USE FOR MY PROJECT?

STATIC?

- BEST POSITIONING PRECISION
- INTEGRATED ADJUSTMENT FOR MULTIPLE STATIONS
- EASY CONTROL DATA CAPTURE (NOT DISTANT DEPENDENT)
- CAN PROVIDE 2 CM ORTHO HEIGHTS
- TAKES LONGER
- NEED TO PROCESS DATA IF DONE IN HOUSE
- OPUS-S & OPUS-RS GIVE POINT POSITIONS, NOT INTEGRATED ADJUSTMENT

REAL TIME?

- FASTEST
- ADEQUATE POSITIONING
- USER MUST BE AWARE OF FIELD PROCEDURES
- USE RT IF THE SITE IS TO BE CALIBRATED
- **RTN** MAY NATIVELY GIVE INADEQUATE ORTHOMETRIC HEIGHTS (BUT USUALLY HORIZONTAL POSITIONS ARE GOOD)
- LESS METADATA
- CAN RECOVER FEATURES, CONTROL, ETC. IN REAL TIME

USING OPUS:
POINT POSITIONING BY NGS

From: opus@ngs.noaa.gov
Sent: Friday, August 24, 2007 8:58 AM
To: Curt.Smith@noaa.gov
Subject: OPUS solution : L1222340.07o 000200294

Attachments: l122234r.07o.xml

t.

ER 19, 2007

NGS OPUS SOLUTION REPORT

=====

USER: Curt.Smith@noaa.gov
RINEX FILE: l122234r.07o

DATE: August 24, 2007
TIME: 14:57:41 UTC

SOFTWARE: page5 0612.06 master12.pl
EPHEMERIS: igr14413.eph [rapid]
NAV FILE: brdc2340.07n
ANT NAME: TRM4800 NONE
ARP HEIGHT: 2.000

START: 2007/08/22 17:25:00
STOP: 2007/08/22 22:26:00
OBS USED: 11651 / 11783 : 99%
FIXED AMB: 42 / 43 : 98%
OVERALL RMS: 0.017(m)

(W)	SCALED
(feet)	ADJUSTED

REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)

ITRF00 (EPOCH:2007.6406)

GEOID03
(feet) COMP
NAVD 88

X:	-1872566.694(m)	0.016(m)	-1872567.435(m)	0.016(m)
Y:	-4326352.439(m)	0.031(m)	-4326351.192(m)	0.031(m)
Z:	4283701.741(m)	0.007(m)	4283701.717(m)	0.007(m)

LAT:	42 27 8.21603	0.013(m)	42 27 8.23405	0.013(m)
E LON:	246 35 44.46740	0.027(m)	246 35 44.41598	0.027(m)
W LON:	113 24 15.53260	0.027(m)	113 24 15.58402	0.027(m)
EL HGT:	1328.228(m)	0.019(m)	1327.585(m)	0.019(m)

aphic map and have

ORTHO F

Northing
Easting
Converge
Point Sc
Combined

US NATIC

PID
AI5649 GTRG GTRG_EBRY_ID1998 CORS ARP
DG9771 P121 HNSLVALLY_UT2004 CORS ARP
DG6570 IDPO POCATELLO CORS ARP

N431438.711	W1131428.314	88985.7
N414812.179	W1124153.795	92771.9
N425155.995	W1122554.287	92030.4

ravity values.

**THE VALUE OF OPUS SAVED THIS SURVEYOR'S
LICENSE AND BUSINESS! OPUS ON BENCH MARKS IS
ALSO VALUABLE TO PLACE ACCURATE POSITIONS ON
LOCATIONS THAT COULD BE JUST SCALED FROM TOPO
MAPS. THIS AIDS IN THE MONUMENT'S RECOVERY
(AND LOCATES THE BENCH MARK ACCURATELY FOR
INPUT INTO THE GEOID MODELING DONE BY NGS)**



OPUS: Online Positioning User Service

National Geodetic Survey

[NGS Home](#)[About NGS](#)[Data & Imagery](#)[Tools](#)[Surveys](#)[Science & Education](#)

OPUS Menu

[Upload](#)[About OPUS](#)[Published Solutions](#)[Contact OPUS](#)[NGS Home](#)[About](#)[OPUS Menu](#)[Upload](#)[About OPUS](#)[Published Solutions](#)[Contact OPUS](#)

Upload your data file.

Tie your GPS observation to the National Spatial Reference System.

What is OPUS? **FAQs**

You selected 2011 frame for processing your observation.

* **Email address** - your solution will be sent here.

* **Data file** of dual-frequency GPS observations. **sample**

 no antenna selected

Antenna type - choosing wrong may degrade your accuracy.

meters above your mark.

Antenna height of your antenna's reference point.

to **customize** your solution.

for data > 15 min. < 2 hrs.

for data > 2 hrs. < 48 hrs.

* required fields

We may use your data for internal evaluations of OPUS use, accuracy, or related research.

passive network is

OPUS-S OUTPUT

NGS OPUS SOLUTION REPORT

=====

USER: william.stone@noaa.gov
RINEX FILE: satt142p.03o

• check ephemeris

EPHEMERIS: igs0198.eph [precise]

NAV FILE: brdc1420.03n

ANT NAME: ASH701975.01B NONE

ARP HEIGHT: 2.0

- > 90% observations used
- > 50% ambiguities fixed
- < 3 cm overall RMS

OBS USED: 5443 / 5491 : 99%
FIXED AMB: 27 / 27 : 100%
OVERALL RMS: 0.011(m)

• check antenna info

REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)

ITRF00 (EPOCH:2003.3882)

X: -1483421.741(m) 0.011(m)
Y: -5020822.786(m) 0.018(m)
Z: 3633944.541(m) 0.011(m)

-1483422.387(m) 0.011(m)
-5020821.428(m) 0.018(m)

• < 5 cm peak-to-peak

LAT: 34 56 43.60684 0.005(m)
E LON: 253 32 24.06657 0.005(m)
W LON: 106 27 35.93343 0.005(m)
EL HGT: 1810.320(m) 0.023(m)
ORTHO HGT: 1830.434(m) 0.034(m)

34 56 43.62530 0.005(m)
253 32 24.02700 0.005(m)
106 27 35.97300 0.005(m)
1809.352(m) 0.023(m)

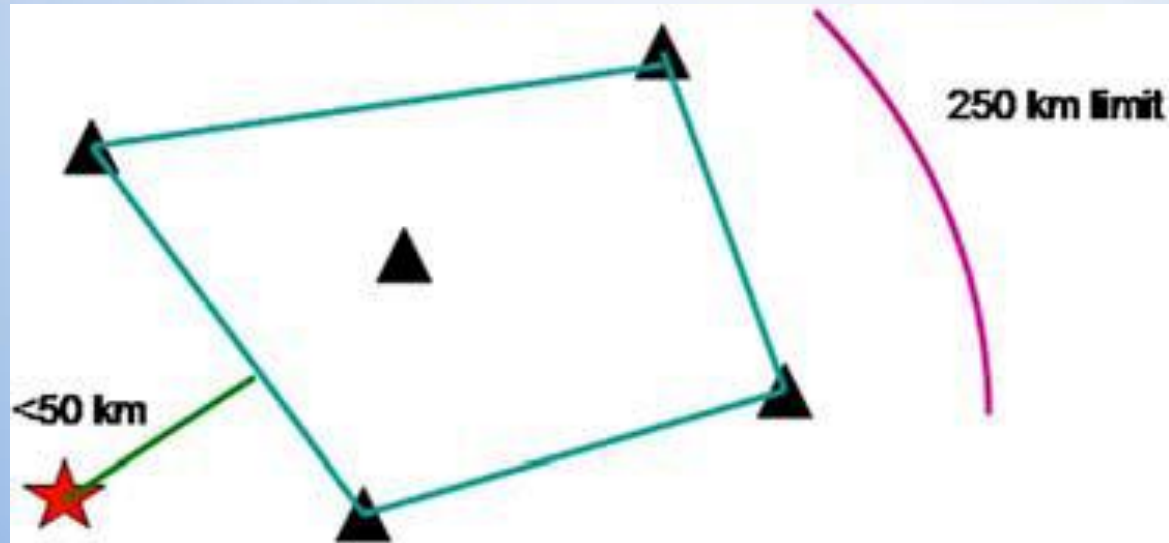
[Geoid03 NAVD88]

...and which CORS were used? ...
might wait and resubmit for improved CORS scenario

OPUS-Rapid Static (OPUS-RS)

- 15-minute to 2-hour sessions
- ties to 3 – 9 CORS (< 250km)
- uses RSGPS vs. PAGES software
- P1/P2 code & L1/L2 phase observations
- resolves all ambiguities with LAMBDA
- similar to Real-Time Network computations
- RSGPS solution modes:
 - network: solves ambiguities, tropo, iono
 - rover: tropo and ion interpolated to rover
- ~10,000 lines of code

OPUS-RS REFERENCE STATION SEARCH ALGORITHM



- Sort stations in CORS network by distance from rover. Select up to nine CORS that are less than 250 km from rover, with suitable data.
- No solution is attempted if fewer than three CORS selected.
- No solution attempted if distance from rover to polygon enclosing selected CORS is greater than 50 km.

OPUS-RS OUTPUT

NGS OPUS-RS SOLUTION REPORT

USER:	william.stone@noaa.gov	DATE:	October 29, 2007
RINEX FILE:	1207287x.07o	TIME:	14:39:04 UTC
SOFTWARE:	rsgps 1.09 RS11.prl 1.12	START:	2007/10/14 23:27:15
EPHEMERIS:	igr14490.eph [rapid]	STOP:	2007/10/15 00:00:15
NAV FILE:	brdc2870.07n	OBS USED:	1962 / 2082 : 94%
ANT NAME:	ASH701975.01A	QUALITY IND.	34.21/ 37.91 *
ARP HEIGHT:	0.0	NORMALIZED RMS:	0.307

REF FRAME:	NAD_83(CORS96)(EPOCH:2002.0000)	ITRF00 (EPOCH:2007.78627)
LAT:	36 2 52.79767 0.008(m)	36 2 52.81498 0.008(m)
E LON:	252 2 18.45532 0.013(m)	252 2 18.41156 0.013(m)
W LON:	107 57 41.54468 0.013(m)	107 57 41.58844 0.013(m)
EL HGT:	1974.304(m) 0.005(m)	1973.396(m) 0.005(m)
ORTHO HGT:	1995.280(m) 0.026(m)	[Geoid03 NAVD88]

"#Fixed Ambiguities" replaced by "Quality Indicator"

- average of W-ratio (separation between candidate of last 3 epochs
- reported as network mode / rover mode
- look for values > 3 for confidence in solution

sets of ambiguities)

OPUS-RS OUTPUT

NGS OPUS-RS SOLUTION REPORT

USER:	william.stone@noaa.gov	DATE:	October 29, 2007
RINEX FILE:	1207287x.07o	TIME:	14:39:04 UTC
SOFTWARE:	rsgps 1.09 RS11.prl 1.12	START:	2007/10/14 23:27:15
EPHEMERIS:	igr14490.eph [rapid]	STOP:	2007/10/15 00:00:15
NAV FILE:	brdc2870.07n	OBS USED:	1962 / 2082 : 94%
ANT NAME:	ASH701975.01A	QUALITY IND.	34.21/ 37.91
ARP HEIGHT:	0.0	NORMALIZED RMS:	0.307 *

REF FRAME:	NAD_83(CORS96)(EPOCH:2002.0000)	ITRF00 (EPOCH:2007.78627)
LAT:	36 2 52.79767 0.008(m)	36 2 52.81498 0.008(m)
E LON:	252 2 18.45532 0.013(m)	252 2 18.41156 0.013(m)
W LON:	107 57 41.54468 0.013(m)	107 57 41.58844 0.013(m)
EL HGT:	1974.304(m) 0.005(m)	1973.396(m) 0.005(m)
ORTHO HGT:	1995.280(m) 0.026(m)	[Geoid03 NAVD88]

“Overall RMS” replaced by “Normalized RMS”

- unitless quantity, “expected” = 1
- aka standard deviation of unit weight
- if > 1, noisy data somewhere
- typically <1, meaning noise less than expected

OPUS-RS OUTPUT

NGS OPUS-RS SOLUTION REPORT

USER:	william.stone@noaa.gov	DATE:	October 29, 2007
RINEX FILE:	1207287x.07o	TIME:	14:39:04 UTC
SOFTWARE:	rsgps 1.09 RS11.prl 1.12	START:	2007/10/14 23:27:15
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NAV FILE:	brdc2870.07n	OBS USED:	1962 / 2082 : 94%
ANT NAME:	ASH701975.01A	QUALITY IND.	34.21/ 37.91
ARP HEIGHT:	0.0	NORMALIZED RMS:	0.307

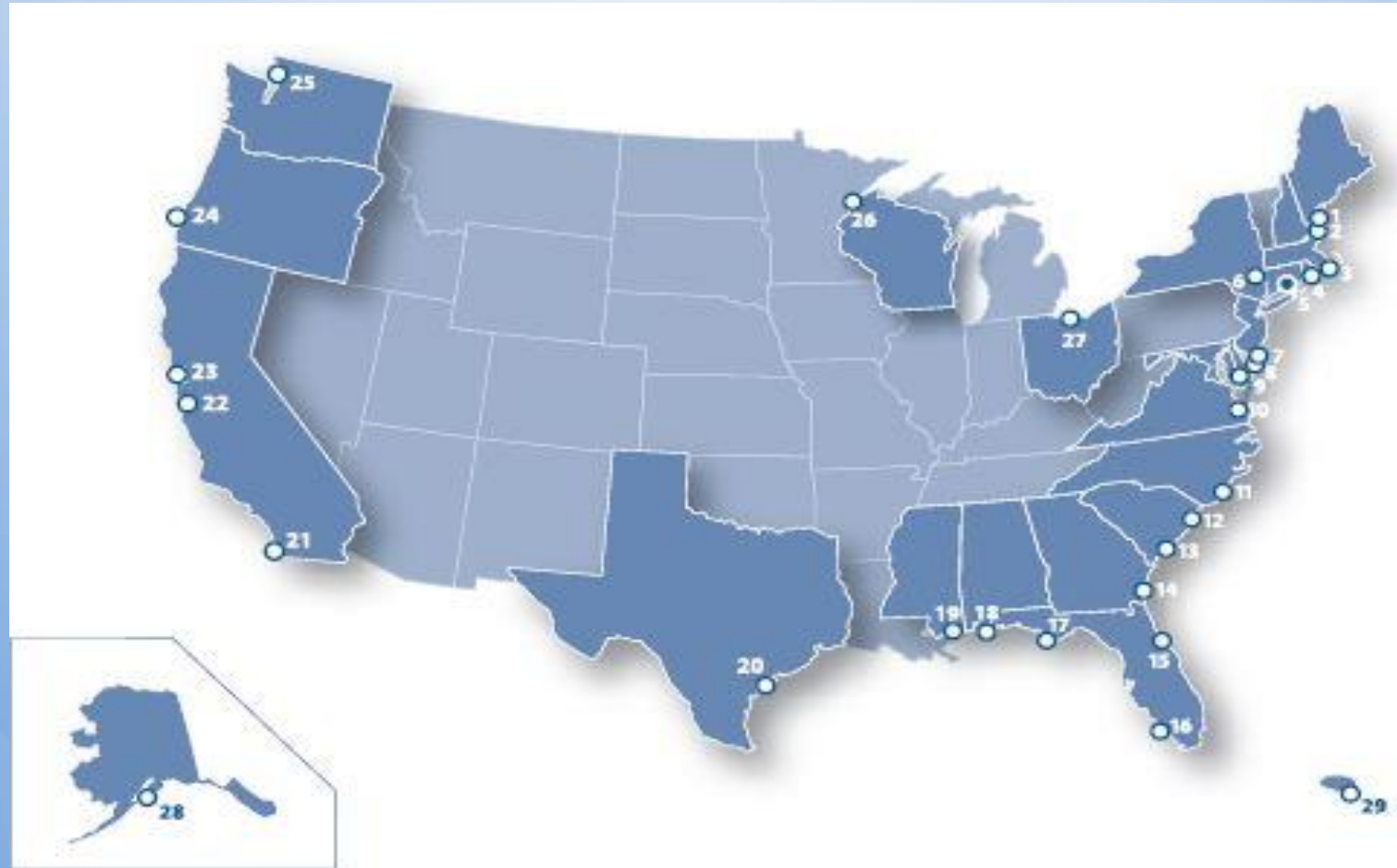
REF FRAME:	NAD_83(CORS96)(EPOCH:2002.0000)	ITRF00 (EPOCH:2007.78627)
LAT:	36 2 52.79767 0.008(m)	36 2 52.81498 0.008(m)
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EL HGT:	1974.304(m) 0.005(m)	1973.396(m) 0.005(m)
ORTHO HGT:	1995.280(m) 0.026(m)	[Geoid03 NAVD88]

Peak-to-Peak replaced by Est. Standard Deviations

- approximately 95% confidence
- derived from scatter of single baseline solutions
- formal standard deviations (optimistic) available in

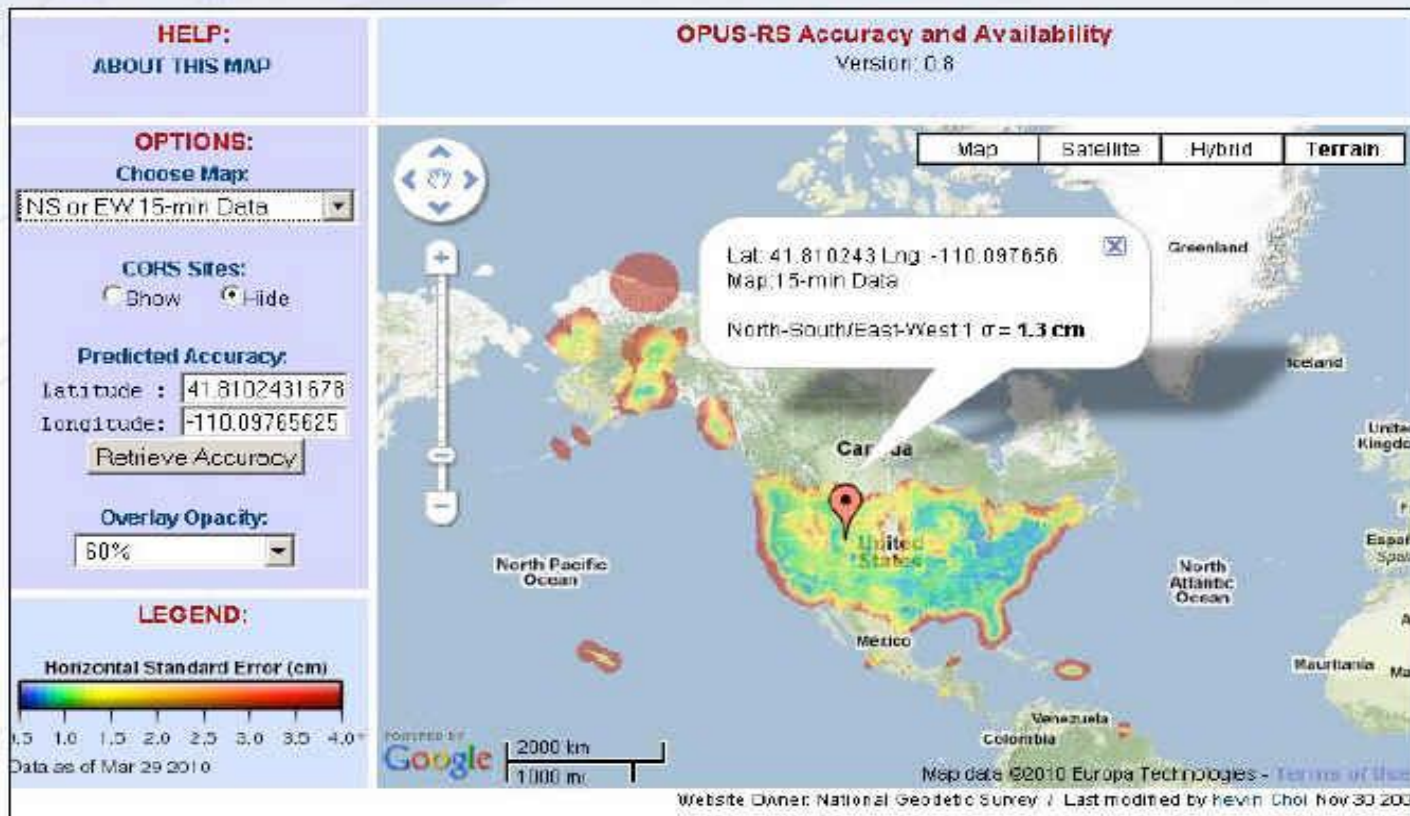
Extended Output

**THE 28 NERRS, BEING ALONG COASTAL REGIONS,
MIGHT HAVE PROBLEMS USING OPUS-RS!**



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

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



OPUS-RS MAP

National Geodetic Survey

HELP:

ABOUT THIS MAP

OPTIONS:

Choose Map:

NS or EW 15-min Data ▾

CORS Sites:

☐ Show ☒ Hide

Predicted Precision:

Latitude : 39.7747933829

Longitude: -89.6411132812

[Retrieve Accuracy](#)

Overlay Opacity:

60% ▾

LEGEND:

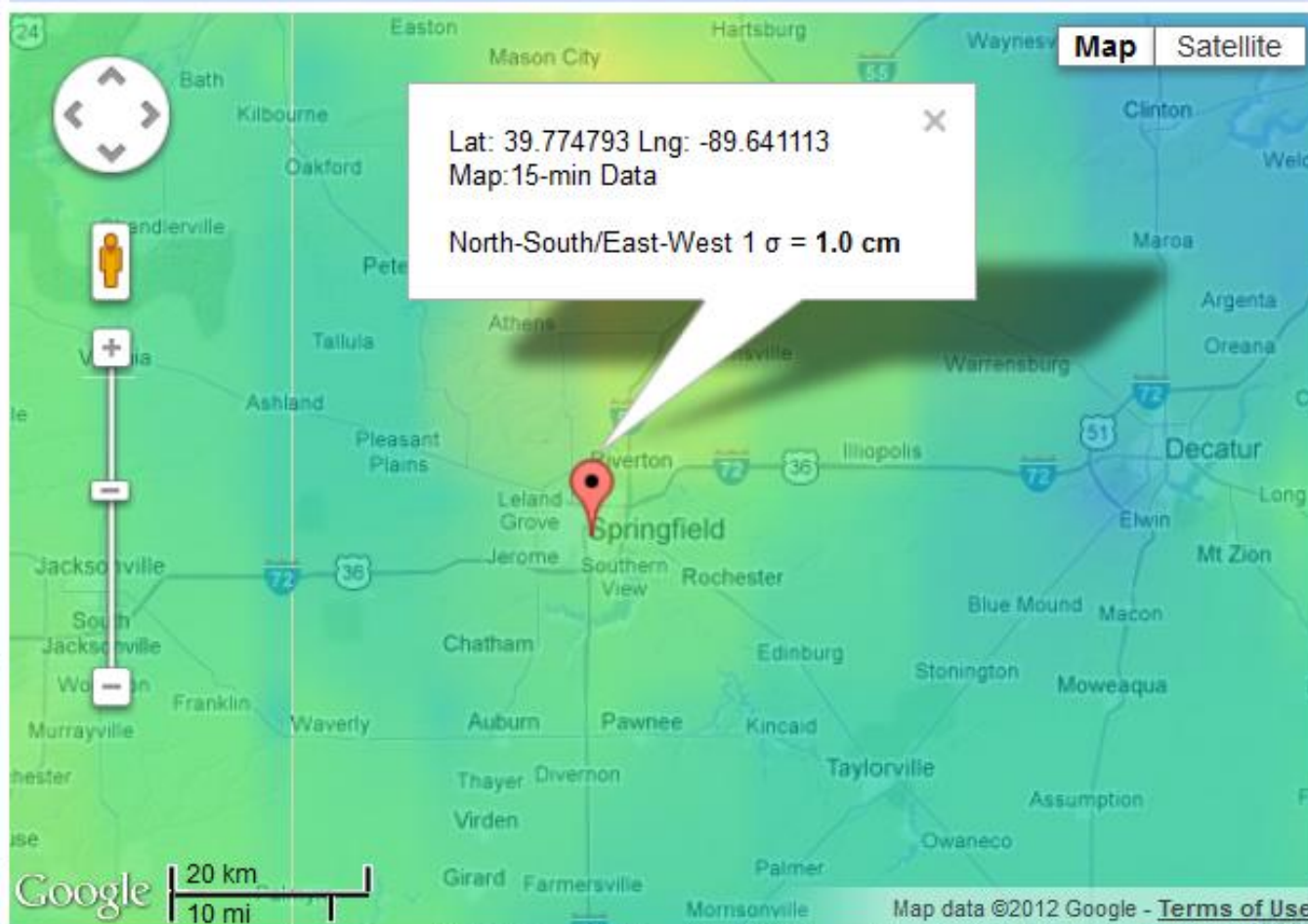
Horizontal 1 STD (cm)



Data as of Feb 13 2012

OPUS-RS Estimated Precision and Availability

Version: 0.85



EDITING RINEX FILES



C:\Presentation\
MAR14\G1031769
ORIGINAL FILE



C:\Presentation\
MAR14\G0000001
TRIM TO FIRST 15 MINUTES



C:\Presentation\
MAR14\G1031500
DELETE BOGUS SITE AND 20
SECOND DATA



C:\Presentation\
MAR14\opusRSretu
OPUS OUTPUT

HEIGHTS FROM NGS 58 & 59 GUIDELINES



NOAA Technical Memorandum NOS NGS-58

GUIDELINES FOR ESTABLISHING GPS-DERIVED ELLIPSOID HEIGHTS
(STANDARDS: 2 CM AND 5 CM)
VERSION 4.3

David B. Zilkoski
Joseph D. D'Onofrio
Stephen J. Frakes

Silver Spring, MD

November 1997

http://www.ngs.noaa.gov/PUBS_LIB/NGS-58.pdf

U.S. DEPARTMENT OF
COMMERCE

National Oceanic and
Atmospheric Administration

National Ocean
Service

National Geodetic
Survey

NOAA Technical Memorandum NOS NGS 59

**Guidelines for Establishing GPS-Derived
Orthometric Heights**

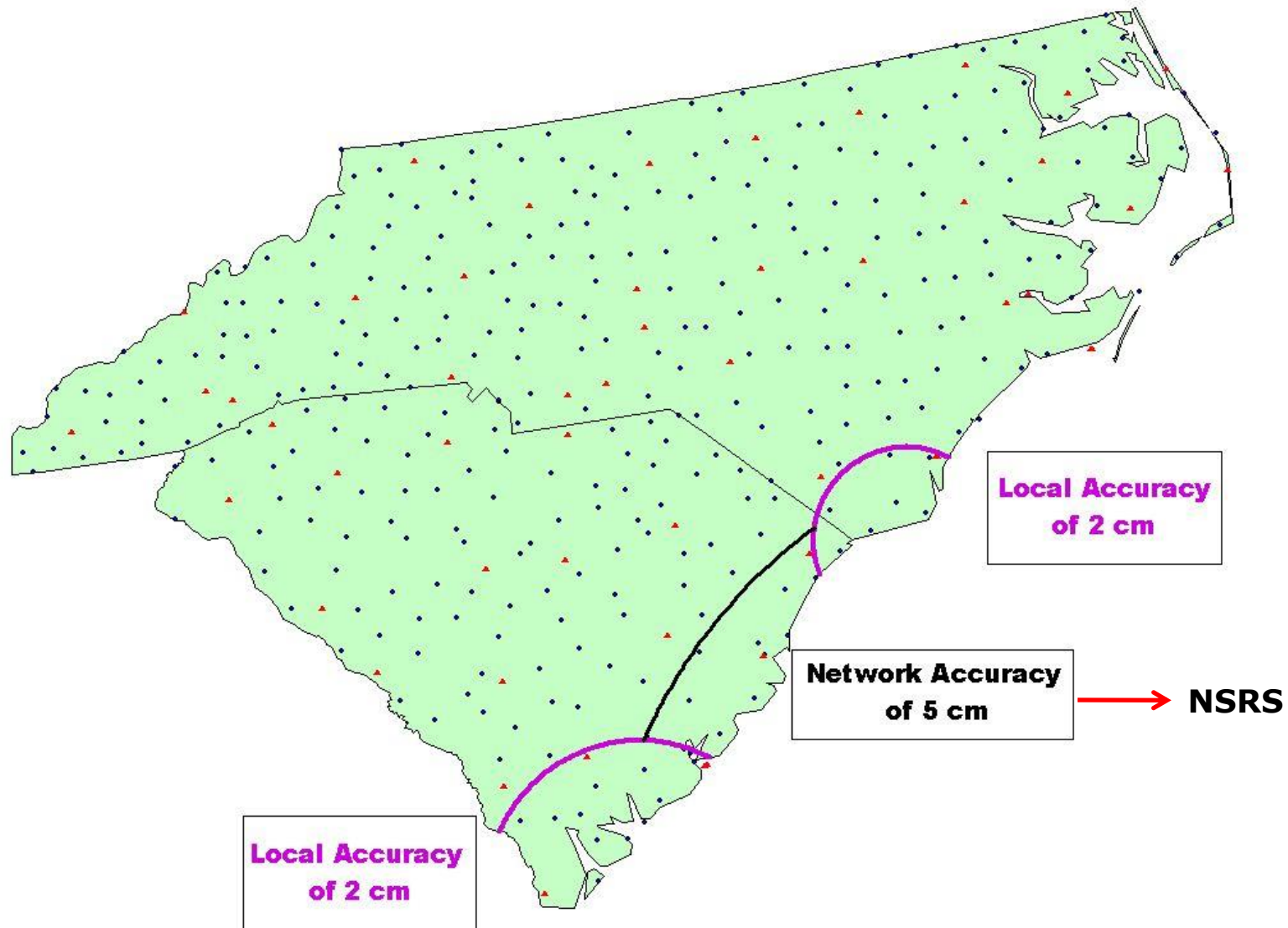
http://www.ngs.noaa.gov/PUBS_LIB/NGS592008069FINAL2.pdf

David B. Zilkoski
Edward E. Carlson
Curtis L. Smith

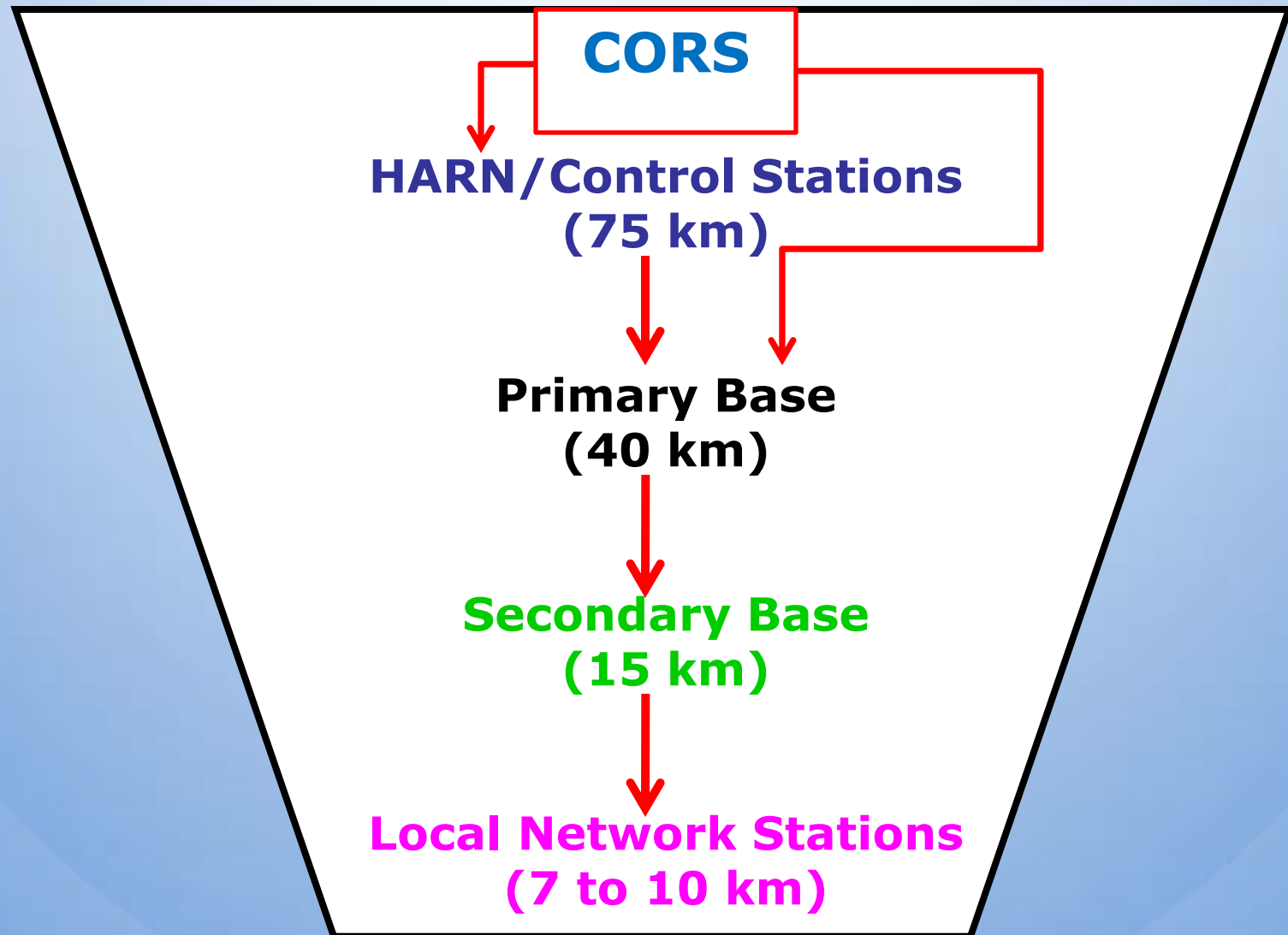
National Geodetic Survey
1315 East-West Highway
Silver Spring, Maryland 20910
(301) 713-3191

26 March 2008

Network / Local Accuracy



GPS ELLIPSOID HEIGHT HIERARCHY



FIELD REQUIREMENTS SUMMARY- FOR HTMOD CAMPAIGNS

- BLUNDERS NOT ALLOWED, SYSTEMATIC ERRORS MUST BE ELIMINATED
- DUAL FREQUENCY RECEIVERS
- GEODETIC ANTENNAS
- FIXED HEIGHT TRIPODS, VERIFY HEIGHT
- 5 HOUR PRIMARY CONTROL OCCUPATIONS WITH MET DATA
- REDUNDANT 30 MINUTE NETWORK CONTROL OCCUPATIONS
- OCCUPY CLOSEST NEIGHBORS
- REDUNDANT OBSERVATIONS
- ★ OCCUPY BENCH MARKS ≤ 20 KM SPACING
- SET ECCENTRICS AS NEEDED
- ★ BASELINES ≤ 10 KM, AVG. 7 KM
- PDOP ≤ 4.0
- PICTURES AND TIES TO MONUMENTS
- COMPLETE LOG FOR EACH OCCUPATION

PLANNING OBSERVATIONS

IX Observation Schedule

IX Observation Schedule							
		NAME	NAME	NAME	NAME	NAME	NAME
		BILL			TOM		JAMES
SESSION	TIME	STATION	STATION	STATION	STATION	STATION	STATION
1	6:30-7:15	GPS 01	GPS 12	MON 37	DISCO DAN	GPS 10 AZ MK	MCDONALD
2	7:45-8:30	VULCAN	GPS 107	V-1724	DISCO DAN	V-1731	MON 60
3	9:00-9:45	MON 4	MON 61	V-1724	MON 39	V-1731	GPS 104
4	10:15-11:00	MON 40	FFX SOUTHWEST	GPS 103	GPS 159	MON 41	GPS 104
5	11:30-12:15	FFX WEST	MON 5	GPS 103	MON 23	V 1673	MON 62
6	12:45-13:30	FFX WEST	MON 63	FLAT RESET	MON 42	V 1673	MON 9
7	14:00-14:45	MON 13	MON 63	FLAT RESET	CNTY BND MKR	V 1650	MON 51
8	15:15-16:00	MON 13	TURBER	V 1653	MON 3	V 1655	V 1643
9	16:30-17:15	MON 49	FFX 12000	GPS 116	GPS 86	V 1655	GPS 157
		NAME	NAME	NAME	NAME	NAME	NAME
	TIME	STATION	STATION	STATION	STATION	STATION	STATION
10	6:30-7:15	MON 49	FFX COUNTY 12000	MON 24	GPS 113	V 1678	GPS 159
11	7:45-8:30	GPS 109	V 1699	MON 24	GPS 113	V 1708	MON 4
12	9:00-9:45	GPS 109	MILL	FFX CNTRL	Z382	GPS 156	V 1782
13	10:15-11:00	MON 8	GPS 155	WEYANOKE	GPS 38	GPS 156	GPS 41

**ESTABLISH A STABLE
ECCENTRIC POINT AND
TRANSFER THE
ORTHOMETRIC HEIGHT
USING PROPER
LEVELING TECHNIQUES**

**Bench Mark
G 506**

BASELINE PROCESSING

- “MULTI-STATION” PROCESSING MODE
- DOUBLE DIFFERENCING (ELIMINATES SAT/RECEIVER CLOCK, HARDWARE BIASES, REDUCES NOISE PARAMETERS)
- PRECISE EPHEMERIS
- 15° CUT OFF (BUT COLLECT AT 10°)
- FIX ALL INTEGERS FOR BASELINES LESS THAN 40 KM
- USE A TROPO MODEL (SELECTED IN SOFTWARE) RATHER THAN FIELD MET DATA UNLESS PROVEN BETTER
- USE RELATIVE TROPO SCALE PARAMETER FOR STATIONS OVER 15 KM AND FOR LARGE INTERSTATION RELIEF
- BASELINE RMS ≤ 1.5 CM
- REDUNDANT BASELINES DIFFER BY ≤ 2.0 CM

ADJUST PRIMARY BASE WITH CONTROL STATIONS FIRST, THEN ADD INTERIOR BASELINES (MINIMUM CONSTRAINED TO FULLY CONSTRAINED. NO GEOID MODEL FOR NGS 58)

THE CYCLE COUNT COOKBOOK-

USING DIFFERENCING TO ELIMINATE OR REDUCE COMMON ERRORS IN THE RECEIVER AND SATELLITE

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

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

ELIMINATED WITH DIFFERENCING

- IONO DELAY
- TROPO DELAY

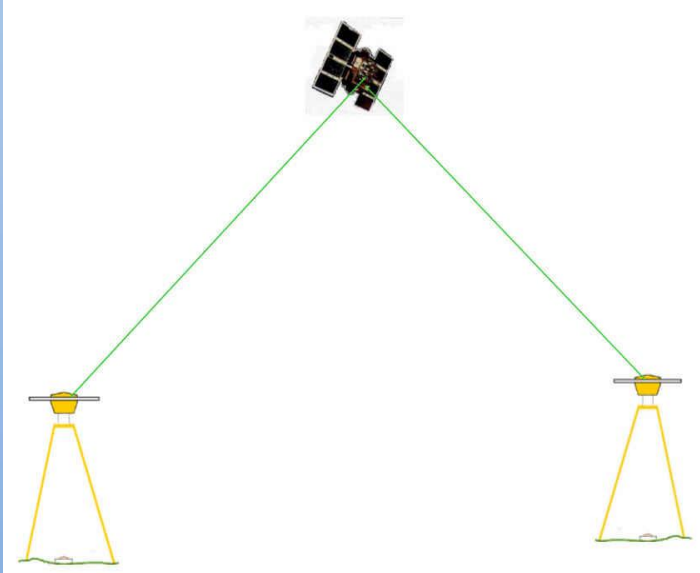
SAME AS BASE WITH SINGLE BASE
INTERPOLATED WITH RTN

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

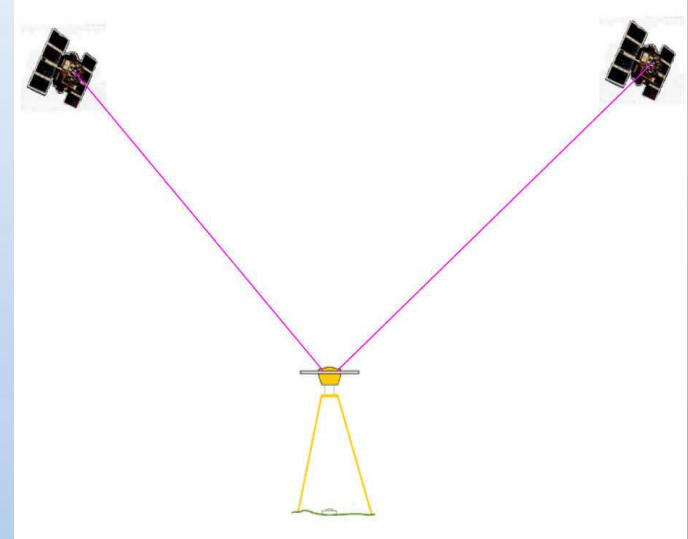
NOT ELIMINATED WITH
DIFFERENCING

SINGLE DIFFERENCE

The satellite clock errors and satellite hardware delays cancel.



**Two receivers, one satellite,
same epoch.
Eliminates satellite clock error,
satellite hardware error**

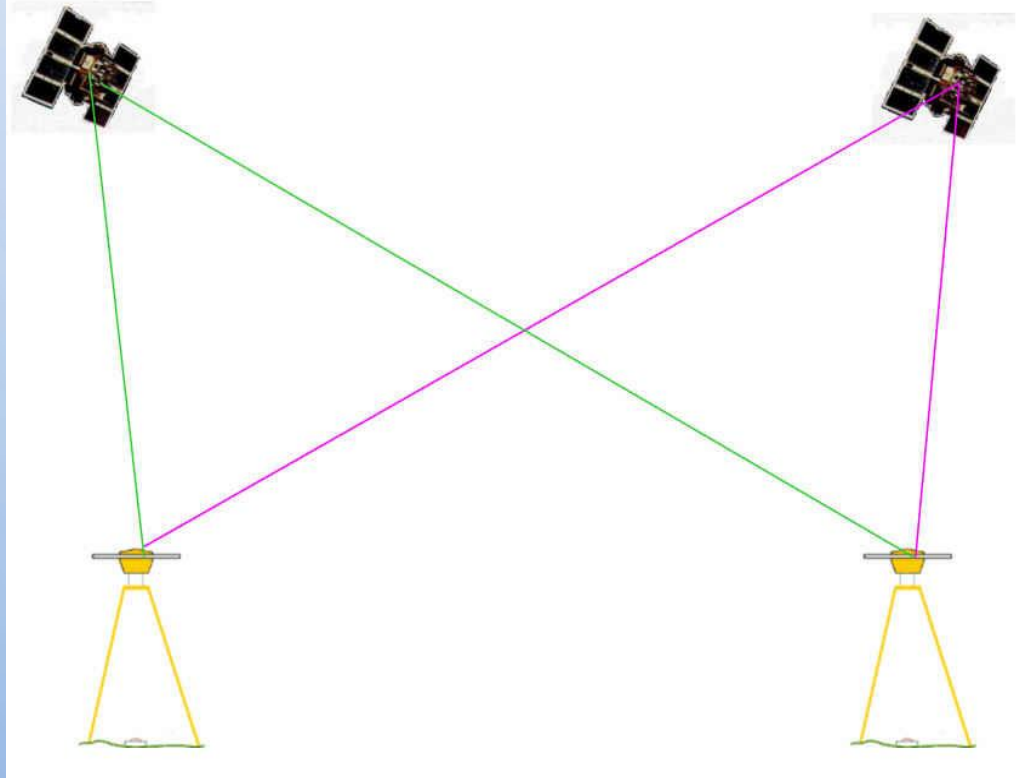


OR

**Two satellites, one receiver
same epoch,
eliminates receiver clock error,
receiver hardware error**

DOUBLE DIFFERENCE

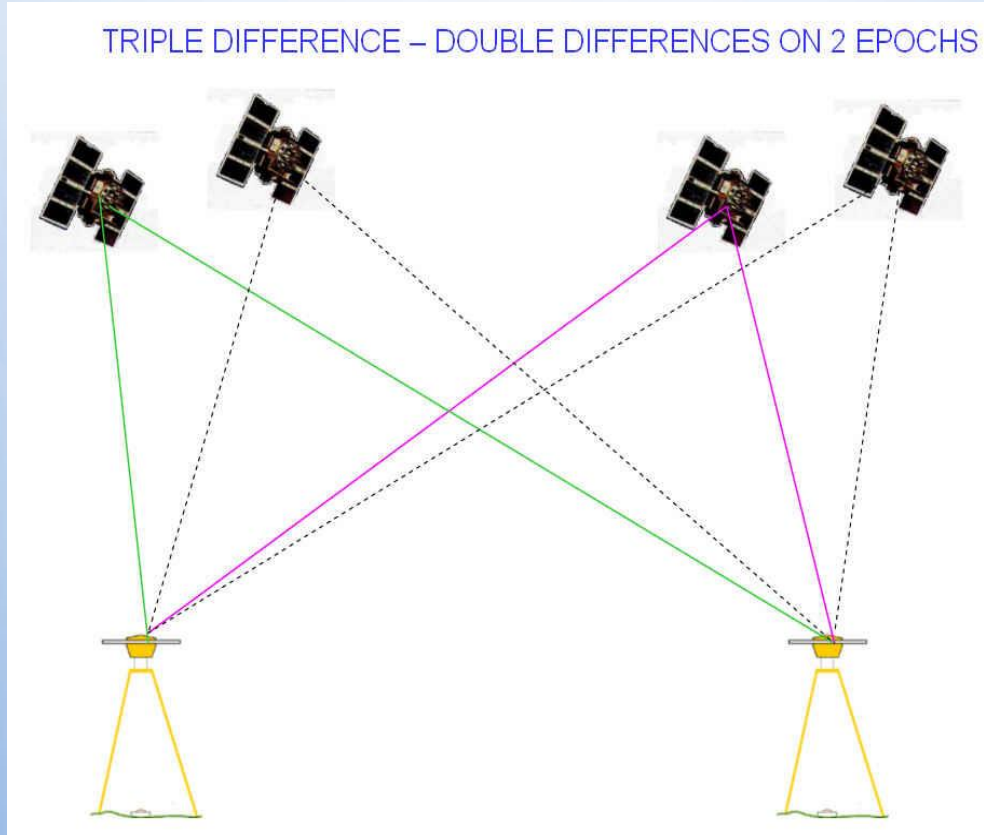
DOUBLE DIFFERENCE – 2 SVNS / 2 RECEIVERS / 1 EPOCH



Double differencing: two receivers, two satellites, same epoch (two Single Differences). Eliminates receiver clock error, receiver hardware error, reduces other errors.

TRIPLE DIFFERENCING

TRIPLE DIFFERENCE – DOUBLE DIFFERENCES ON 2 EPOCHS



Triple difference – difference of two double differences at two epochs for two satellites and two receivers. Detects cycle slips

RESULTING DIFFERENCED PHASE OBSERVABLE (CYCLES)

$$\varphi_k^p(t) = \frac{f}{c} \rho_k^p(t) - \cancel{\int \dot{d}_{k,s}(t) dt} - \cancel{f \dot{d}_{k,s}(t)} - \cancel{I_{k,s}^p} - \boxed{I_{k,\varphi}^p(t) + \frac{f}{c} T_k^p(t)} + \cancel{d_{k,s}(t)} + \cancel{\dot{d}_{k,s}(t)} + \cancel{d_{k,\varphi}^p(t)} + \cancel{\dot{d}_{k,\varphi}^p(t)} + \varepsilon_\varphi$$

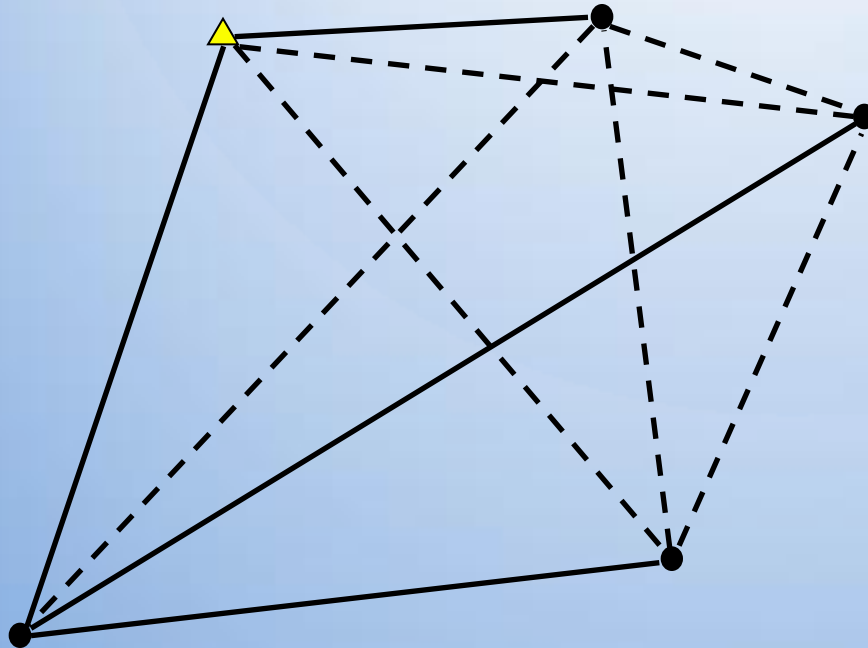
Superscripts refer to the satellite, subscripts refer to ground station

**LEAVES MULTIPATH,
MEASUREMENT NOISE
& RANGE TO
SATELLITE**

ASSUMED THE SAME FOR
ROVER & BASE

OR MODELED BY RTN

INDEPENDENT BASELINES IN GPS



of Baselines =

$$\frac{N(N-1)}{2}$$

**# of Independent
Baselines = $(N-1)$**

N = Number of receivers observing simultaneously



Adobe Acrobat
Document

TGO

BASELINE PROCESSING REPORTS



Adobe Acrobat
Document

TBC

STANDARD ERROR OF UNIT WEIGHT = NETWORK/BASELINE REFERENCE FACTOR WHERE “A POSTERIORI” ERRORS ARE COMPARED TO “A PRIORI” WEIGHTINGS. A VALUE OF “1” MEANS THE NETWORK/BASELINE ADJUSTMENT MATCHED THE WEIGHTINGS PERFECTLY. ANOTHER WAY OF SAYING THIS FOR A NETWORK, MIGHT BE THAT IT’S A NETWORK PICTURE OF ALL THE NORMALIZED RESIDUALS OF THE OBSERVATIONS.

REFERENCE VARIANCE = SQUARE OF THE STD ERROR OF UNIT WEIGHT. SIMILAR TO COVARIANCE

RATIO = COMPARES THE BEST SOLUTION TO THE NEXT BEST. TYPICALLY THIS SHOULD BE ≥ 3 .

ROOT MEAN SQUARE (RMS) = THE SPREAD OF THE MEASUREMENTS RELATIVE TO THE ADJUSTED VALUE OF A BASELINE OR POINT.

STATIC PROCESSING VARIABLES TO IMPROVE SESSION POST PROCESSING

- **USE OTHER REDUNDANT BASELINES FOR THE SAME POINT PAIR**
- **INDEPENDENT BASELINES (N-1)- DON'T USE BAD BASELINES, SELECT OTHER BASELINES FROM THE SESSION**
- **RAPID/PRECISE EPHEMERIS- ESPECIALLY FOR VERTICALS**
- **RAISE CUT OFF ANGLE- BUT DON'T CUT OUT TOO MUCH DATA**
- **EDIT SATELLITE DATA- DISABLE NOISY SATS, DATA**
- **REOBSERVE WITH BETTER PLANNING, HIGHER ANTENNA**

BASELINE ADJUSTMENT SUMMARY

Adjusted Geodetic Coordinates

Errors are reported using 2.58s.

Statistical Summary

Successful Adjustment in 1 iteration(s)

Network Reference Factor : 1.00

Chi Square Test ($\alpha=95\%$) : PASS

Degrees of Freedom : 1027.00

GPS Observation Statistics

Reference Factor : 1.00

Redundancy Number (r) : 1027.00

Point Name	Latitude	N error	Longitude	E error	Height	h error	Fix
REMO	38°44'36.39173"N	0.000m	77°08'39.87408"W	0.000m	-5.450m	0.000m	Lat Long h
OMGA	38°45'11.31240"N	0.000m	77°07'40.60426"W	0.000m	-21.040m	0.000m	Lat Long h
HM16	38°45'54.07930"N	0.013m	77°05'40.71817"W	0.013m	5.888m	0.011m	
H508	38°56'37.39647"N	0.016m	77°08'59.04358"W	0.016m	46.238m	0.014m	
4987	38°58'07.78368"N	0.016m	77°08'21.72380"W	0.016m	14.670m	0.016m	
2305	39°01'00.31786"N	0.000m	77°12'18.26226"W	0.000m	79.640m	0.000m	Lat Long h
HM29	38°59'48.45697"N	0.014m	77°13'49.40683"W	0.014m	82.378m	0.015m	
SHAW	39°03'14.23347"N	0.012m	77°16'59.27011"W	0.012m	61.641m	0.011m	

Chi-Square = test to give a pass/fail grade to the adjustment.

This test compares the actual statistical results to the expected theoretical results (that is, a standard error of unit weight of 1.0) given the number of degrees of freedom in the network. (Degrees of freedom equal the number of observations minus the number of unknowns in the network.)

(Definition paraphrased from CalTrans)

B58	0.72	1.76					
HM18	38°50'05.64604"N	0.016m	77°07'41.37354"W	0.016m	36.500m	0.014m	
G151	38°50'35.77432"N	0.019m	77°06'35.17729"W	0.018m	23.995m	0.015m	
HOPT	38°59'45.18521"N	0.000m	77°18'45.84871"W	0.000m	80.550m	0.000m	Lat Long h
HM27	39°01'28.58699"N	0.015m	77°20'33.86629"W	0.014m	96.598m	0.012m	
HM28	39°03'09.79941"N	0.019m	77°20'12.24386"W	0.019m	69.516m	0.014m	
1633	38°59'07.22725"N	0.017m	77°20'57.96047"W	0.015m	94.499m	0.023m	
F520	38°42'53.08709"N	0.021m	77°02'48.60023"W	0.021m	-24.042m	0.024m	
HM17	38°47'20.55764"N	0.016m	77°06'45.34079"W	0.016m	40.546m	0.013m	
G149	38°51'37.91057"N	0.017m	77°07'39.95309"W	0.017m	44.700m	0.014m	
INTK	39°03'46.55701"N	0.000m	77°20'34.73047"W	0.000m	27.110m	0.000m	Lat Long h
NC25	38°56'48.06097"N	0.000m	77°22'09.84060"W	0.000m	91.430m	0.000m	Lat Long h
HM25	38°57'36.61450"N	0.013m	77°24'12.90930"W	0.013m	88.844m	0.011m	
FXES	38°55'43.18409"N	0.000m	77°08'47.67513"W	0.000m	52.410m	0.000m	Lat Long h
HM24	38°56'24.22205"N	0.014m	77°21'20.58815"W	0.013m	103.526m	0.012m	
Z287	38°59'25.41926"N	0.013m	77°16'21.55524"W	0.013m	67.913m	0.015m	
HM11	38°51'19.95979"N	0.012m	77°18'48.59078"W	0.011m	84.482m	0.010m	
G159	38°49'01.15743"N	0.012m	77°21'36.80383"W	0.012m	73.412m	0.011m	

I. ORTHO HEIGHT ADJUSTMENT STEPS (NGS 59)

- **PERFORM 3-D MINIMUM-CONSTRAINT LEAST SQUARES ADJUSTMENT OF GPS SURVEY PROJECT**
 - **CONSTRAIN 1 LATITUDE, 1 LONGITUDE, 1 ORTHOMETRIC HEIGHT
(RECALL THAT ELLIPSOID HEIGHTS HAVE ALREADY BEEN ANALYZED AND ADJUSTED)**
 - **CURRENT HYBRID GEOID MODEL IS APPLIED**
- **ANALYZE ADJUSTMENT RESULTS FROM BP-1**
 - **DETECT AND REMOVE ALL DATA OUTLIERS**

II. ORTHO HEIGHT ADJUSTMENT STEPS (NGS 59)

- **COMPUTE DIFFERENCES BETWEEN GPS-DERIVED ORTHOMETRIC HEIGHTS FROM MINIMUM-CONSTRAINT ADJUSTMENT IN BP-2 AND PUBLISHED NAVD88 ORTHOMETRIC HEIGHTS FOR ALL KNOWN BENCH MARKS**

CONTROL SON

Control Coordinate Comparisons

Values shown are control coord minus adjusted coord.

Point Name	ΔNorthing	ΔEasting	ΔElevation	ΔHeight
REMO	0.010m	0.018m	N/A	-0.019m
OMGA	-0.006m	0.016m	N/A	-0.017m
H508	N/A	N/A	N/A	N/A
2305	0.005m	0.017m	N/A	-0.009m
HOPT	-0.020m	-0.010m	N/A	0.014m
F520	N/A	N/A	N/A	N/A
INTK	0.003m	0.010m	N/A	N/A
NC25	0.014m	0.015m	N/A	-0.026m
FXES	0.013m	0.015m	N/A	-0.042m
Z287	N/A	N/A	N/A	N/A
FX12	N/A	N/A	N/A	N/A
1708	N/A	N/A	N/A	N/A
DSCO	0.009m	0.003m	N/A	-0.024m
FXSW	0.005m	-0.005m	N/A	-0.033m
1650	N/A	N/A	N/A	N/A
TRBR	0.004m	0.024m	N/A	N/A
1724	N/A	N/A	N/A	N/A
FLTR	0.009m	0.047m	N/A	N/A
FXWE	0.006m	0.003m	N/A	-0.023m
EA3D	N/A	N/A	N/A	N/A
POWH	0.013m	0.011m	N/A	0.017m
VLCN	N/A	N/A	N/A	N/A

OUTLIERS?

- **PASSIVE CONTROL QUALITY (OVER TIME)**
- **GEOID MODEL QUALITY**

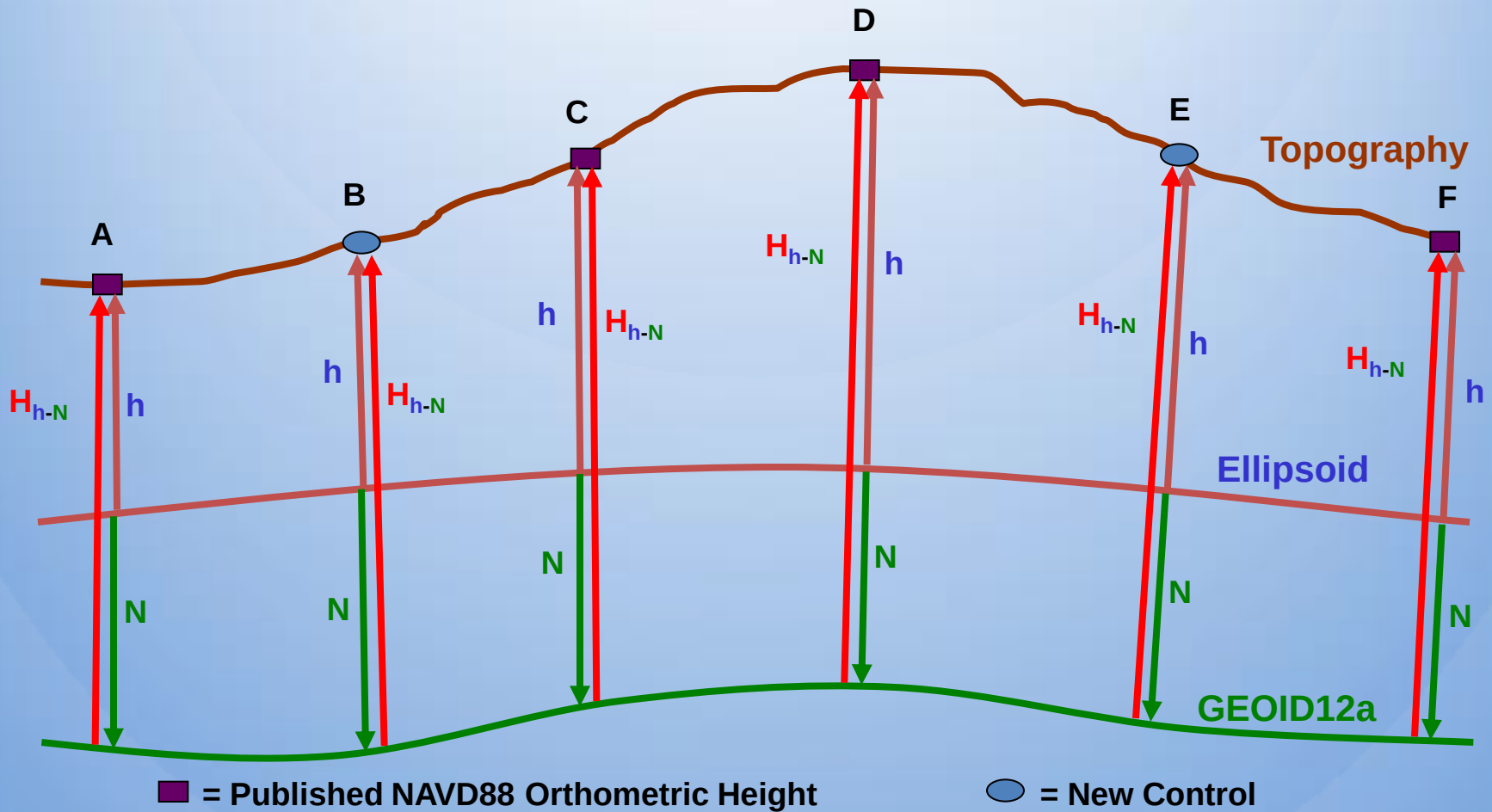
III. ORTHO HEIGHT ADJUSTMENT STEPS (NGS 59)

- **Determine which BMs have *valid* NAVD88 height values from results from BP-3 and should be fixed**
 - Differences need to agree 2 cm for 2 cm survey
 - Differences need to agree 5 cm for 5 cm survey
 - May detect systematic tilt over large areas
 - Solve for geoidal slope and scale
- **Perform constrained adjustment with results from BP-4**
 - Constrain 1 latitude, 1 longitude, all valid orthometric height values. Add orthos a few at a time.
 - Ensure final heights not distorted in adjustment

ADJUSTMENT

- EVALUATE VERTICAL CONTROL
- MINIMALLY CONSTRAINED ADJUSTMENT – VERIFIES FIELD DATA CONSISTENCY
- FULLY CONSTRAINED ADJUSTMENT – PLACES PROJECT ON NAVD 88/NAD 83 PASSIVE MARKS
- GOAL IS 2 CM NAVD 88 HEIGHTS BETWEEN NETWORK MONUMENTS (LOCAL ADJUSTMENT)

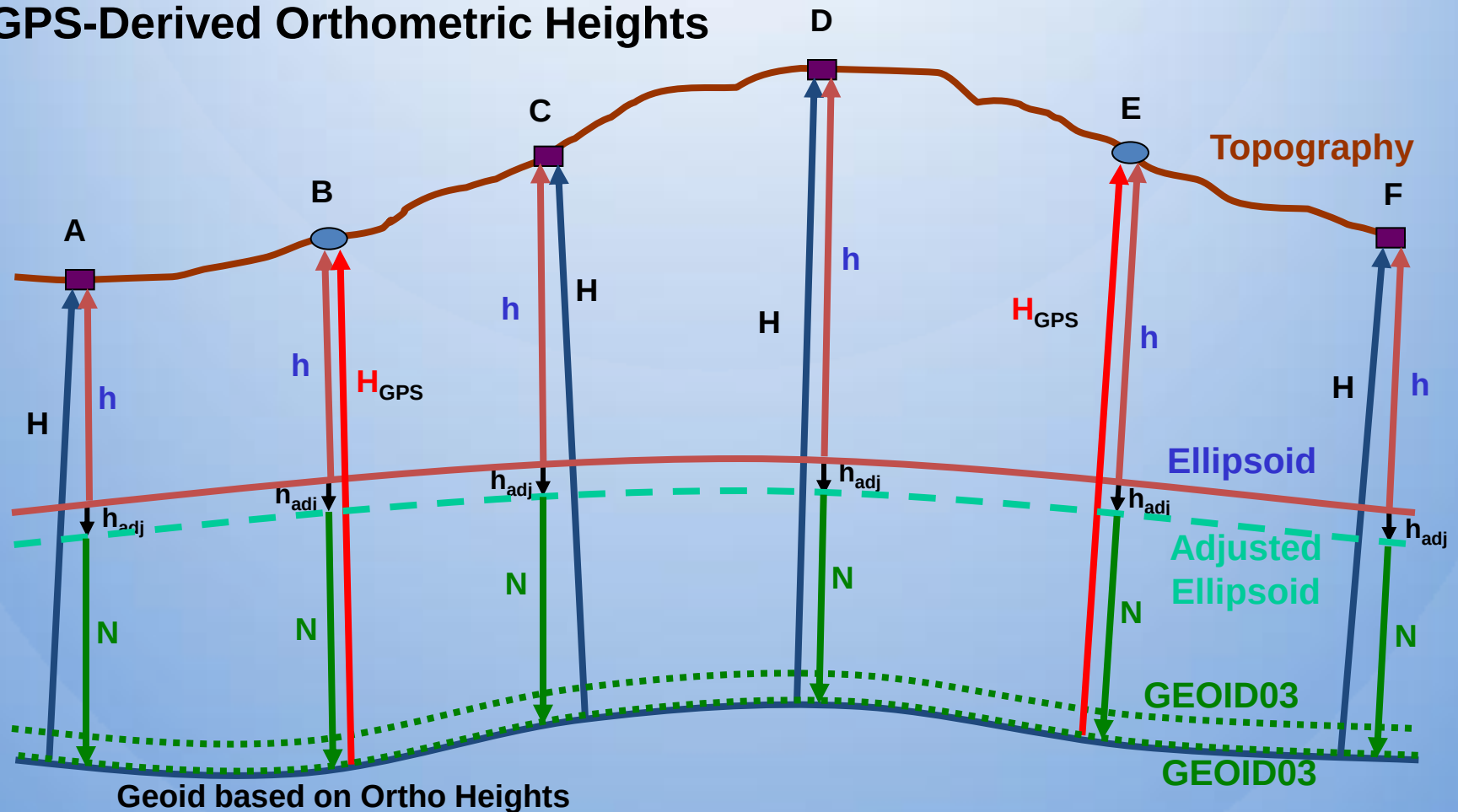
GPS-DERIVED HEIGHTS FROM GEOID03 SEPARATION



CONSTRAINED VERTICAL ADJUSTMENT

Ellipsoid Height Adjusted to Fit Constrained Orthometric Heights + N

GPS-Derived Orthometric Heights



■ = Published NAVD88 Orthometric Height ○ = New Control

DH3699 HT MOD - This is a Height Modernization Survey Station.
DH3699 DESIGNATION 3608E02
DH3699 PID - DH3699
DH3699 STATE/COUNTY- MO/PEMISCOT
DH3699 USGS QUAD - STEELE (1976)

DH3699 *CURRENT SURVEY CONTROL

DH3699* NAD 83 (1997) - 36 00 00.84824 (N) 089 49 52.22461 (W) ADJUSTED

DH3699* NAVD 88 - 77.54 (meters) 254.4 (feet) GPS OBS

DH3699 X - 15,222.070 (meters) COMP
DH3699 Y - -5,166,000.892 (meters) COMP
DH3699 Z - 3,728,241.823 (meters) COMP
DH3699 LAPLACE CORR- 0.42 (seconds) DEFLEC99
DH3699 ELLIP HEIGHT- 49.33 (meters) (05/31/05) GPS OBS
DH3699 GEOID HEIGHT- -28.19 (meters) GEOID03

DH3699 HORZ ORDER - FIRST

DH3699 ELLP ORDER - FOURTH CLASS II

DH3699 The horizontal coordinates were established by GPS observations

DH3699 and adjusted by the National Geodetic Survey in May 2005..

DH3699 The orthometric height was determined by GPS observations and a
DH3699 high-resolution geoid model using precise GPS observation and
DH3699 processing techniques.

DH3699 The X, Y, and Z were computed from the position and the ellipsoidal ht.
DH3699

DH3699 The Laplace correction was computed from DEFLEC99 derived deflections.

DH3699

DH3699 The ellipsoidal height was determined by GPS observations

DH3699 and is referenced to NAD 83.

DH3699

DH3699 The geoid height was determined by GEOID03.

DH3699

DH3699;
DH3699; SPC MO E - North East Units Scale Factor Converg.
DH3699; UTM 16 - 18,724.696 310,300.091 MT 0.99997812 +0 23 35.3
DH3699; UTM 16 - 3,987,682.411 244,801.459 MT 1.00040255 -1 39 54.1
DH3699!
DH3699! SPC MO E - Elev Factor x Scale Factor = Combined Factor
DH3699! UTM 16 - 0.99999226 x 0.99997812 = 0.99997038
DH3699! UTM 16 - 0.99999226 x 1.00040255 = 1.00039480

**Identified as
Height Mod
survey station**

**Elevation
published
to centimeters**

**Orthometric
height
determined by
GPS**

RECOMMENDATIONS FOR ESTABLISHING SITE ELEVATIONS FOR FLOOD CERIFICATION WORK:

- **USE STATIC GNSS PROCEDURES**
- **IF YOU HAVE THREE OR MORE RECEIVERS, OCCUPY AT LEAST TWO “GOLDEN” NAVD 88 BMs (LA = C4G STATIONS) CONCURRENTLY WITH THE SITE POINTS (THREE RECEIVERS = MOVE FROM SITE POINT A TO SITE POINT B, THEN OCCUPY SITE POINTS CONCURRENTLY)**
- **KEEP A FIELD LOG WITH THE PROPER METADATA**
- **HAVE REDUNDANCY SPACED BY 4 HOURS TIME OF DAY**
- **CHECK WITH OPUS– S AND OPUS– RS**
- **USE FIXED HEIGHT POLES**
- **MAKE SURE THE CORRECT ANTENNA AND HEIGHT IS ENTERED INTO OPUS OR YOUR PROCESSING SOFTWARE**
- **IF A COLLAPSIBLE TRIPOD MUST BE USED, MEASURE THE HEIGHT BEFORE, AT MIDPOINT AND AT THE END OF THE SESSION. MEASURE IN METERS AND FEET FOR A CHECK**
- **A CHECK MAY ALSO BE DONE USING RT PROCEDURES**
- **LEAVE TWO GOOD TBMs SOMEWHERE NEARBY AS REFERENCE ELEVATIONS FOR THE DWELLING HEIGHTS.**

GPS BASICS: LEARNING HOW GPS WORKS & HOW TO USE IT CORRECTLY



MSS 2014 PART 4: COMBINING GNSS DATA WITH CONVENTIONAL DATA

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Prop LS.



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Combining GPS & Conventional Measurements

Maryland Society of Surveyors
Conference

October 18, 2014

Gaithersburg, Maryland

By

Alan R. Dragoo Maser Consulting

Why Do We Want to Do This

- To allow GPS to contribute to the accuracy of the conventional measurements.
- To allow conventional measurements to validate the quality of the GPS.
- To improve the integrity of the GPS.

What is the First Step

- Decide on a coordinate system
 - State Plane Coordinates
 - Develop your own coordinate system
 - Local Transverse Mercator Projection
 - Approximate Latitude
 - Approximate Longitude
 - Average Elevation
 - Local Ground Level Projection
 - Approximate Latitude
 - Approximate Longitude
 - Average Elevation

Other Choices for a Coordinate System

- No Projection Scale Factor of 1.000000

What Items Are Needed For a Projected Coordinate System

- Ellipsoid
- A developable surface
 - A surface that can be made flat without stretching, or compressing it. (you can cut it)
 - Cone
 - Cylinder
 - Plane
- Geoid (optional)

What is Needed for No Projection Scale Factor of 1.000000

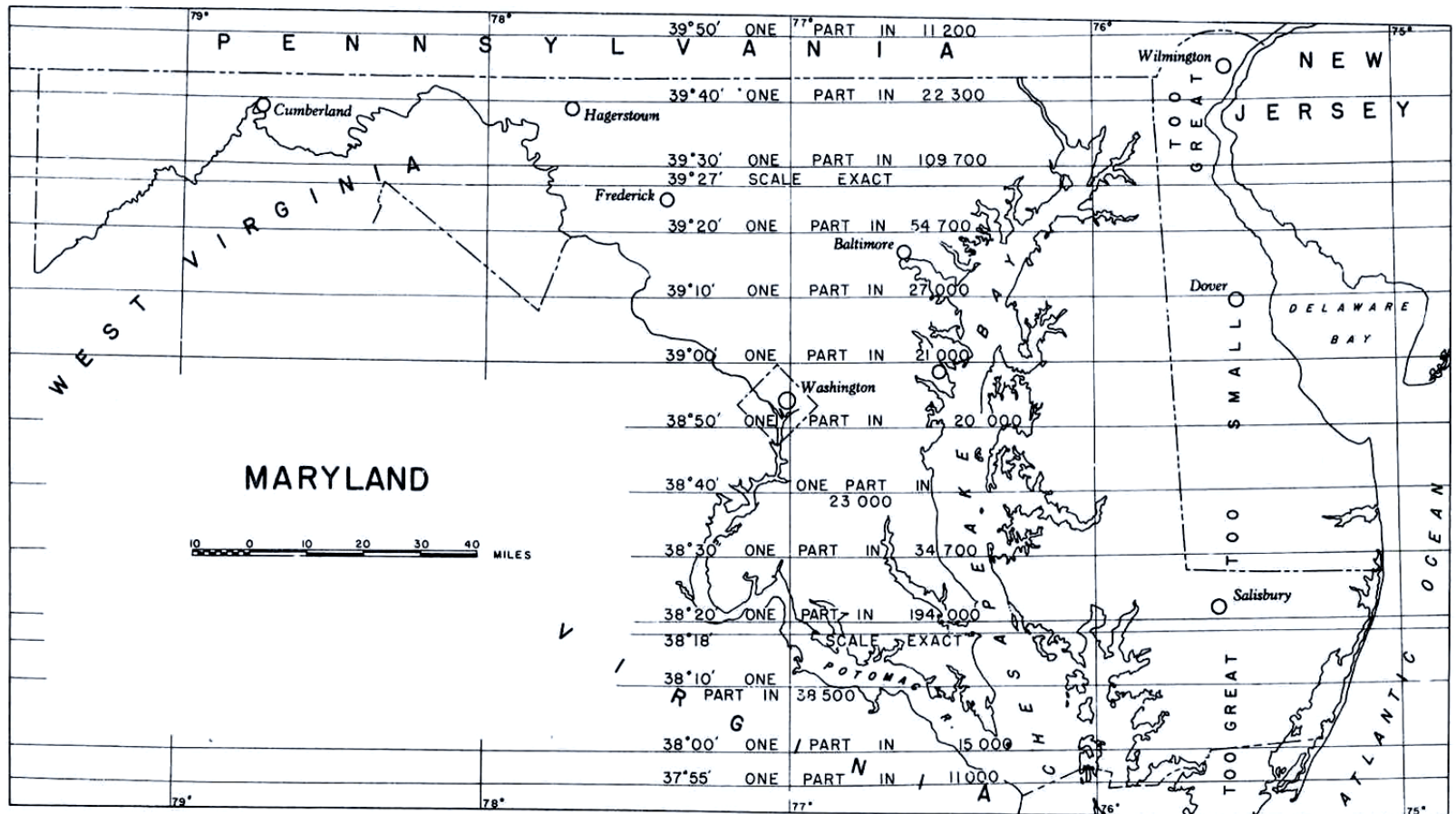
- Starting Coordinate
- Starting Azimuth

Combining GPS and Conventional Measurements

- Using No Projection Scale Factor of 1.000000
 - As the size of your project gets larger the differences in grid coordinates and their measurements on the ground get larger.
 - Because of this GPS (grid) and conventional measurements (ground) can only be used in a project that has no projection over a relatively small area.

How Big is a Small Area?

- How much distortion (error) can you allow?



STATE PLANE-COORDINATE SCALE FACTORS

So You Are Going to Use a Projection?

- State Plane Coordinates
- Local Transverse Mercator Projection
- Local Ground Level Projection

Using A Projection

- Establish your projection at the start of your project.
- Base your projection on your GPS work if you have GPS work.
- You do this first because if you do it later any coordinates that you calculate will not change to your new coordinate system if you change it later.

How to Create a Local Ground Level Projection From State Plane Coords

- Do the Math by determining the distance between two points across your project.

$$\frac{\textit{Ground Distance}}{\textit{Grid Distance}} = \textit{Scaling Factor}$$

- Scale your entire project by this amount from a central point.
- Offset or truncate your new coordinates so you don't think they are State Plane Coordinates later.
- TEST IT !!!

Advantage of Using a Projection

- There is no distortion (error) between GPS and conventional measurements.

Questions?

