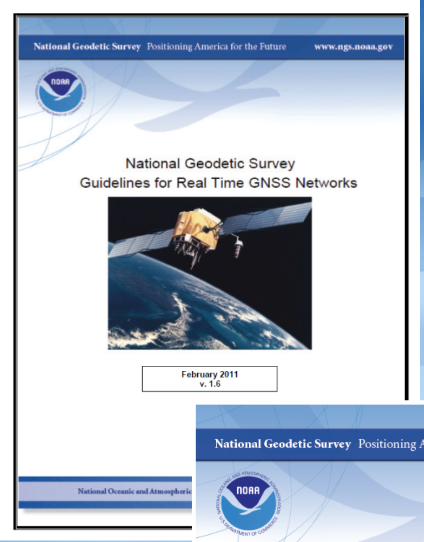
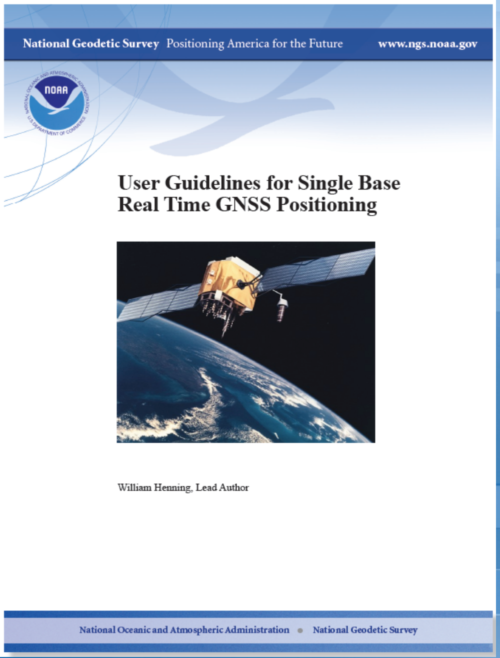
National Geodetic Survey

GNSS POSITIONING-STATIC & REAL-TIME SEMINAR


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

National Geodetic Survey
Guidelines for Real Time GNSS Networks

February 2011
v. 1.6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User Guidelines for Single Base
Real Time GNSS Positioning

William Henning, Lead Author

National Oceanic and Atmospheric Administration • National Geodetic Survey

REAL TIME GNSS POSITIONING BEST METHODS FIELD GUIDE

LSU LOUISIANA STATE UNIVERSITY

Center for GeoInformatics - Louisiana State University

LSRC "Positioning Louisiana for the future"

National Oceanic and Atmospheric Administration

Bill Henning
Geodesist, PLS.

WORKSHOP PLAN

CHANGE AS A WAY OF LIFE

↓

HOW RT POSITIONING WORKS – BEYOND THE BLACK BOX

↓

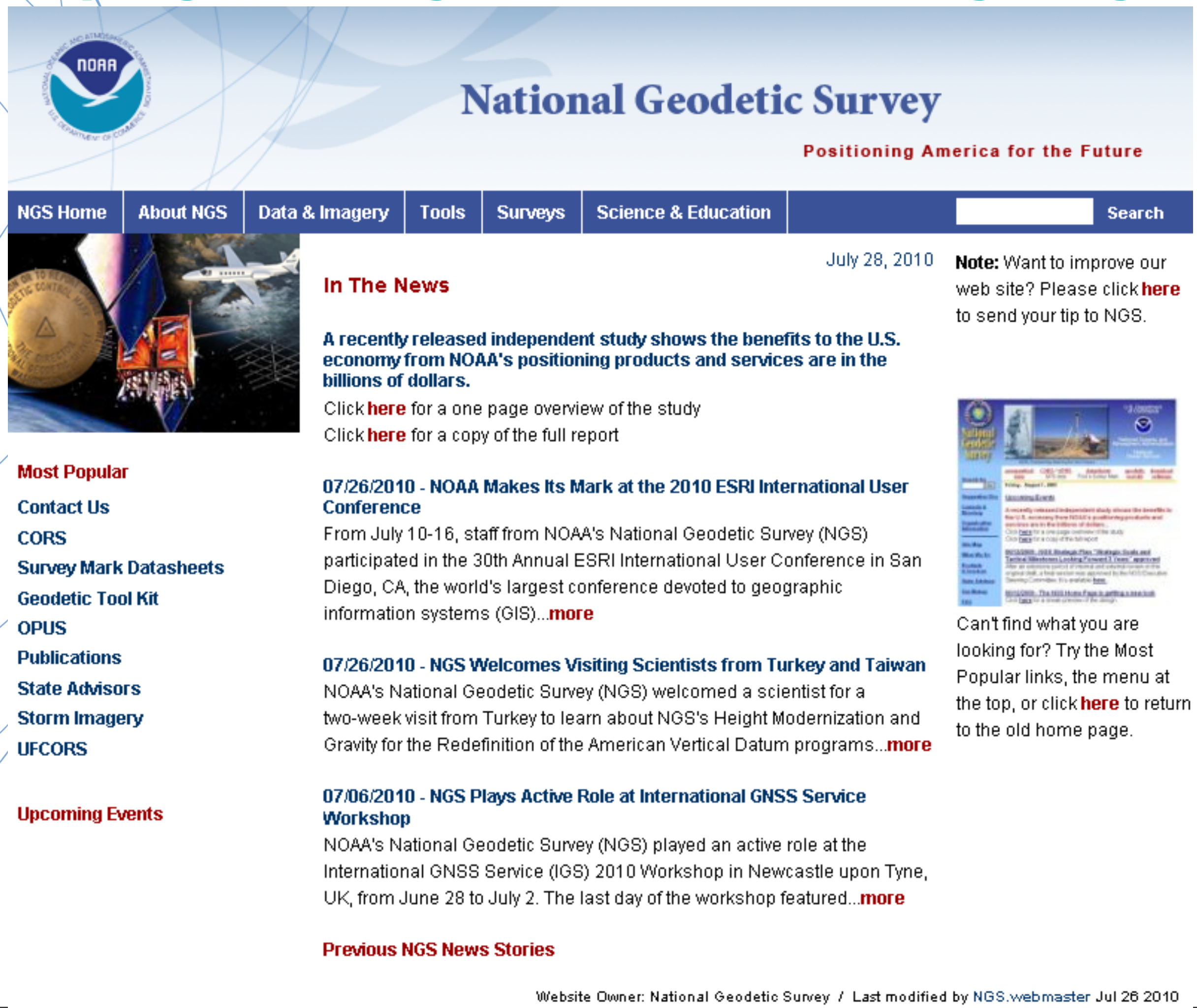
WHAT AFFECTS OUR RT POSITIONING?

↓

BEST METHODS FOR THE FIELD

LINK TO SLIDES:

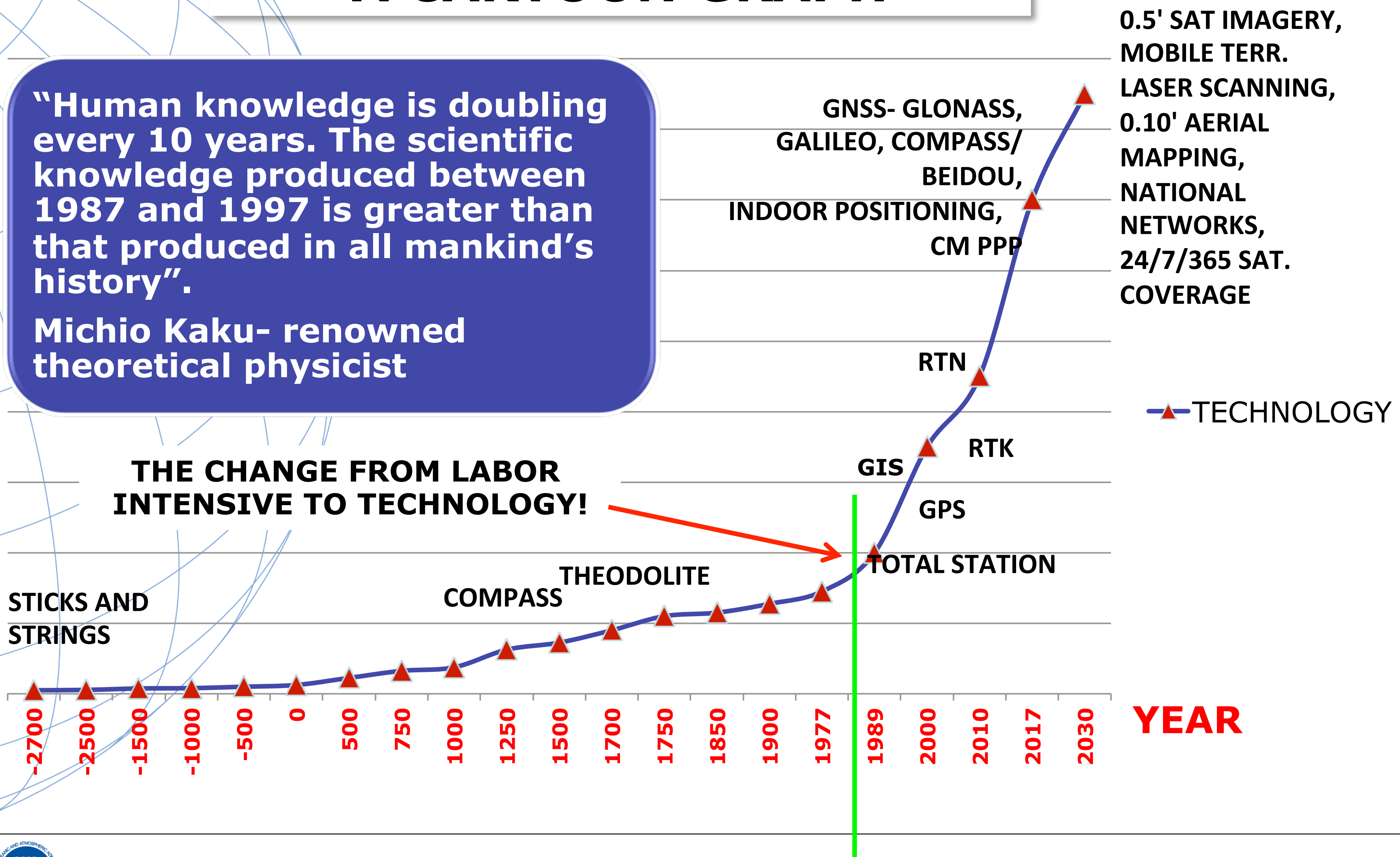
ftp://ftp.ngs.noaa.gov/dist/whenning/c4g2011/

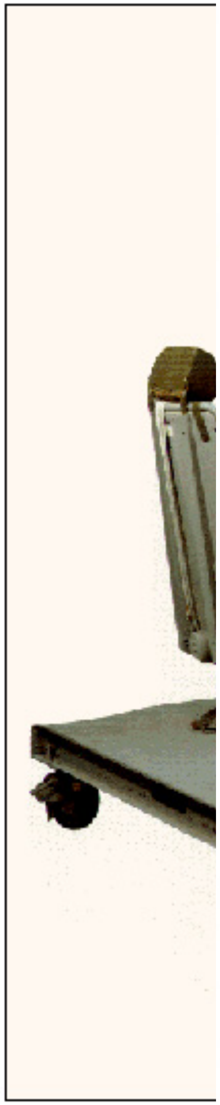


POSITIONING TECHNOLOGY- A CARTOON GRAPH

"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



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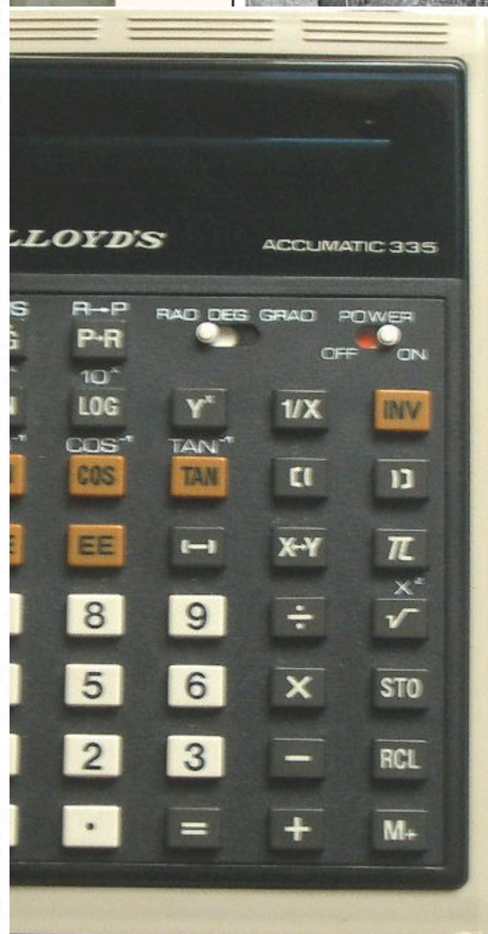
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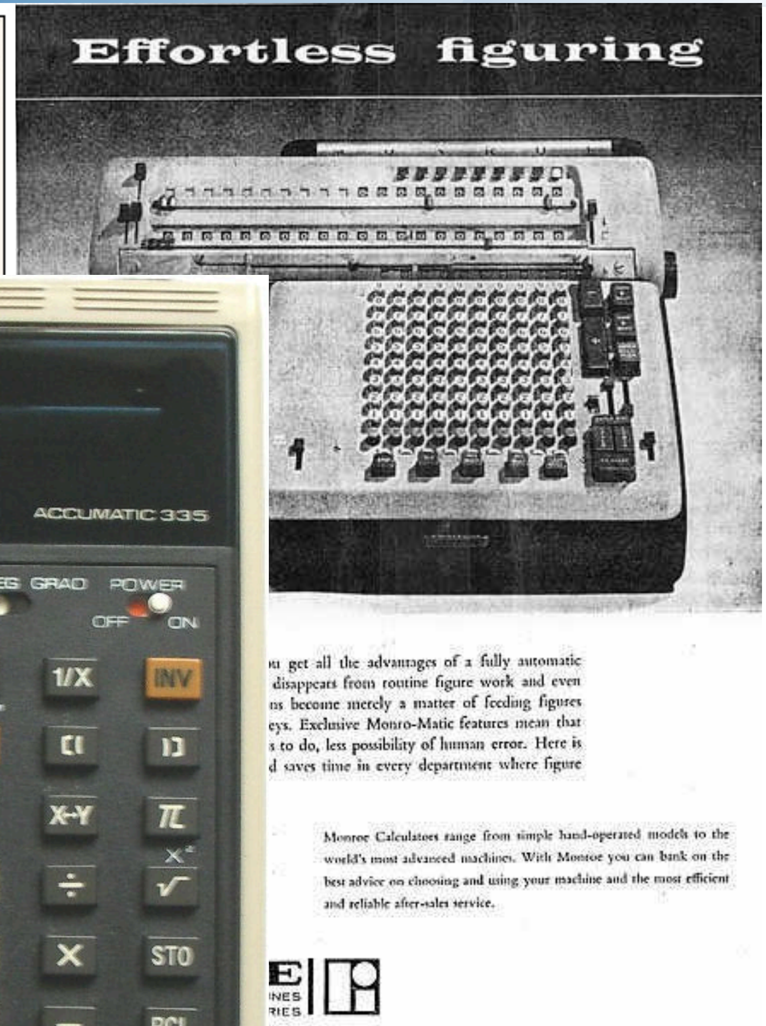
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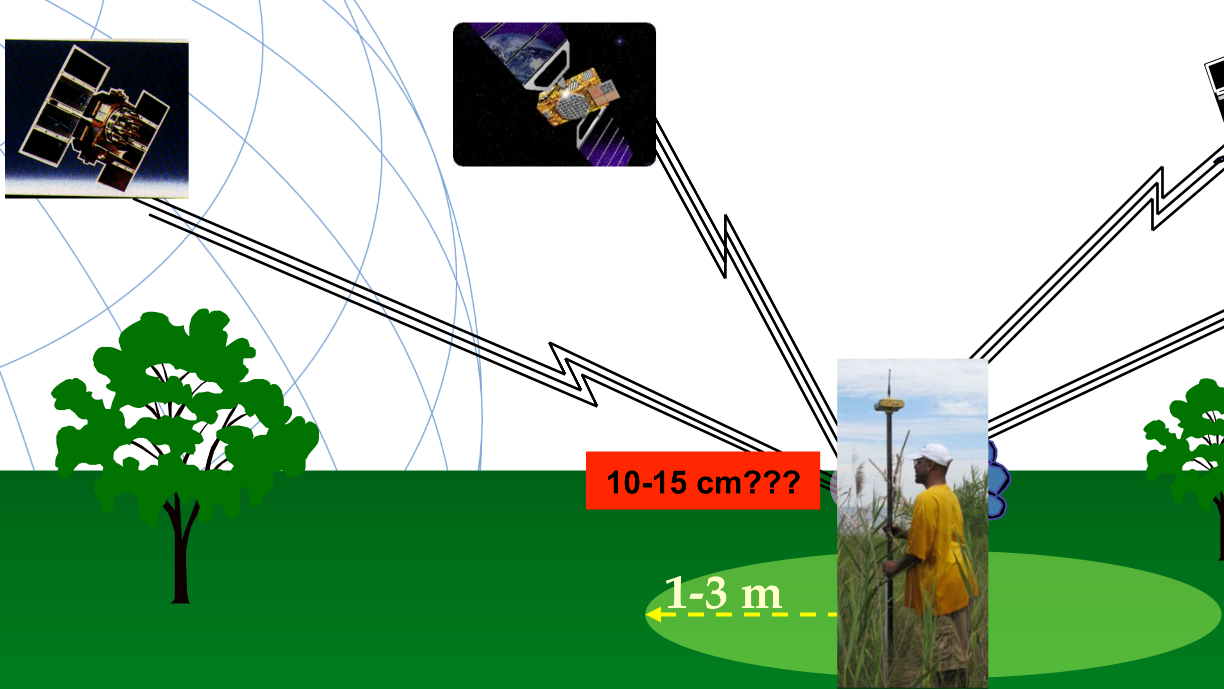
CHANGES IN GNSS



GPS:

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

BETTER RESISTANCE TO INTERFERENCE

FASTER AMBIGUITY RESOLUTION

AUGMENTED CODE APPLICATIONS

GLONASS- FULL OPERATIONAL CAPABILITY 2010
EUROPEAN UNION - GALILEO
CHINA – COMPASS/BEIDOU
JAPAN- QZSS FIRST LAUNCH 2010

= 115 SATELLITES?

THOUGHTS FROM THE 2010 SURVEY SUMMIT

LAWRIE JORDAN, FOUNDER OF ERDAS DIRECTOR OF IMAGERY AT ESRI

In less than five years, every square inch of the Earth will be imaged (by satellites) constantly. He said we are already half-way there.

Transformation from using imagery as a backdrop to extracting information from it.

STUART RICH, CHIEF TECHNOLOGY OFFICER OF PENOBSCOT BAY MEDIA, LLC

Only 16% of cities are mapped with a big vacuum being building interior maps in urban areas

Lack of attention on underground infrastructure mapping.

GROUND PENETRATING RADAR (GPR)
GNSS, INS, PHOTOGRAMMETRY, CAMERA PAIR MATCH TO BUILDING FACADES- TERRESTRIAL LIDAR INFO.

GNSS TECHNOLOGY

SURVEYING

GEODESY

ENGINEERING

REMOTE SENSING

MAPPING

“GEOSPATIAL PROFESSIONAL”

CM LEVEL PRECISION/ ACCURACY

AROUND 2020 AUTONOMOUS GNSS POSITIONING MAY BE BETTER THAN 2-DM (SAY 0.5’)

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

NGS SINGLE BASE GUIDELINES

WHY SINGLE-BASE?

-ACCOMMODATE LEGACY USERS

- CLOSEST BASE NETWORKS

-AREAS WITH NO CELL COVERAGE

- PROJECT SITE APPLICATIONS, SUCH AS MACHINE CONTROL

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

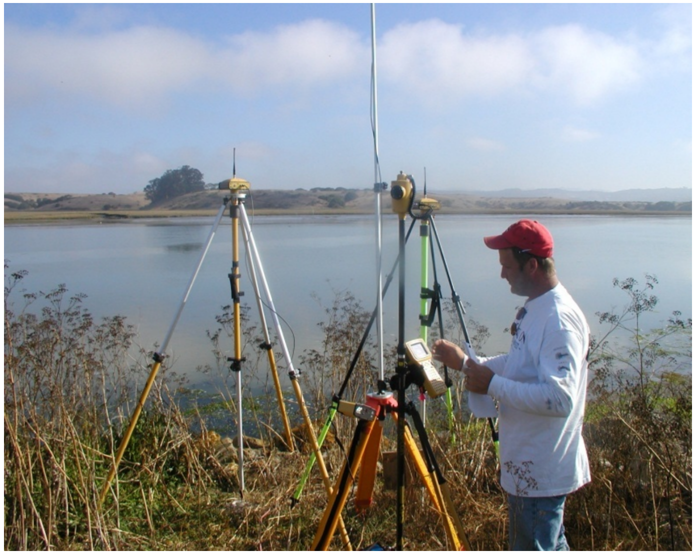
User Guidelines for Single Base Real Time GNSS Positioning

William Henning, Lead Author

National Oceanic and Atmospheric Administration • National Geodetic Survey

http://www.ngs.noaa.gov/PUBS_LIB/pub_GPS.shtml

THE USE OF RTK- A CONFLUENCE OF TECHNOLOGY



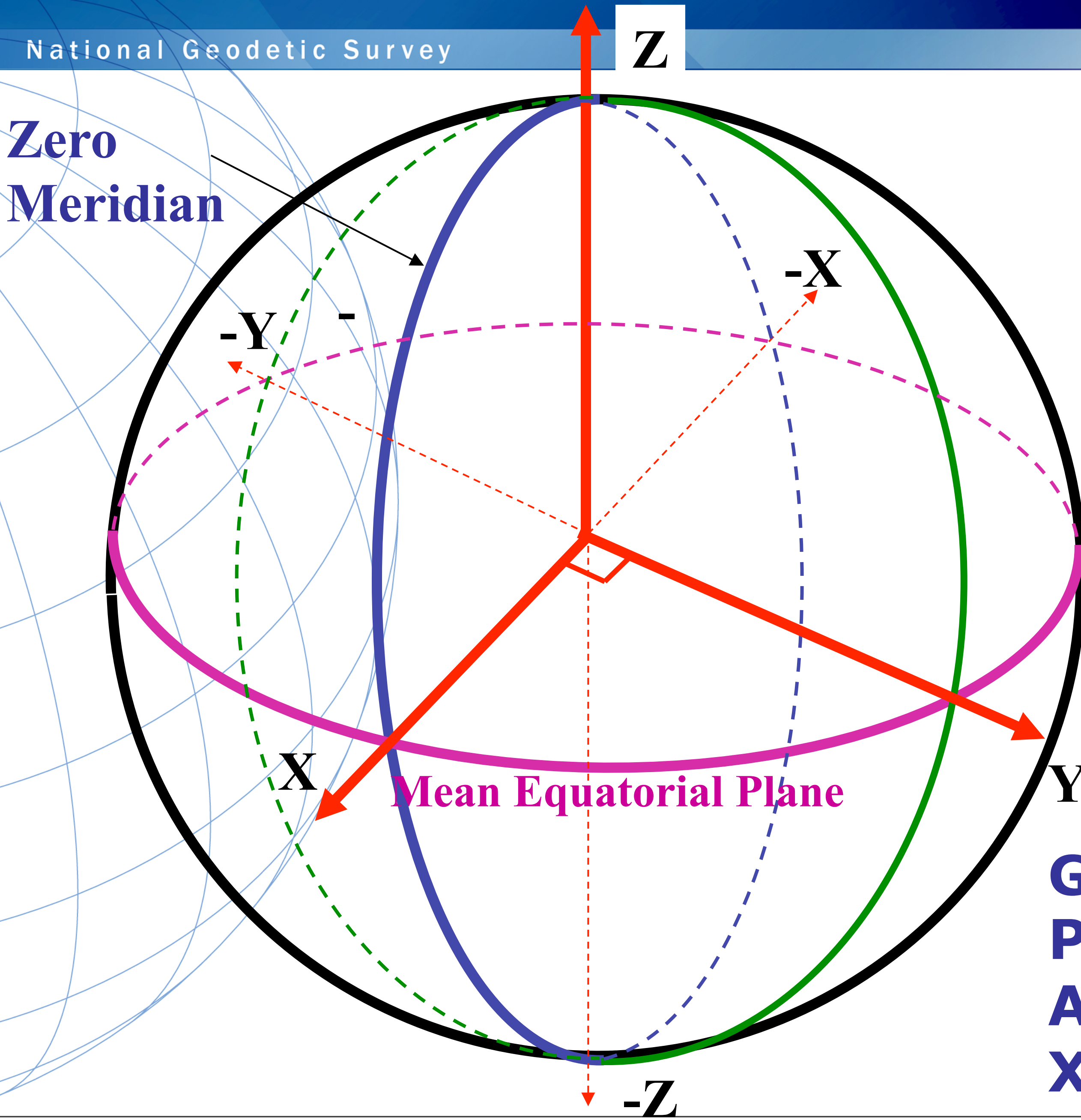
- INTERNET DATA VIA CELL TECHNOLOGY
- SOFTWARE/FIRMWARE ALGORITHMS
- GNSS HARDWARE
- SATELLITE CONSTELLATIONS
- SATELLITE CODES/FREQUENCIES

THE THREE BASE STATION OPTIONS FOR 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



DATUM=

- ***SURFACE***
- **ORIENTATION**
- **ORIGIN**
- **SCALE**

+ GRAVITY

e^2 = first eccentricity squared = $2f - f^2$

GNSS POSITIONS ARE ECEF, XYZ

HOW DOES RT WORK?

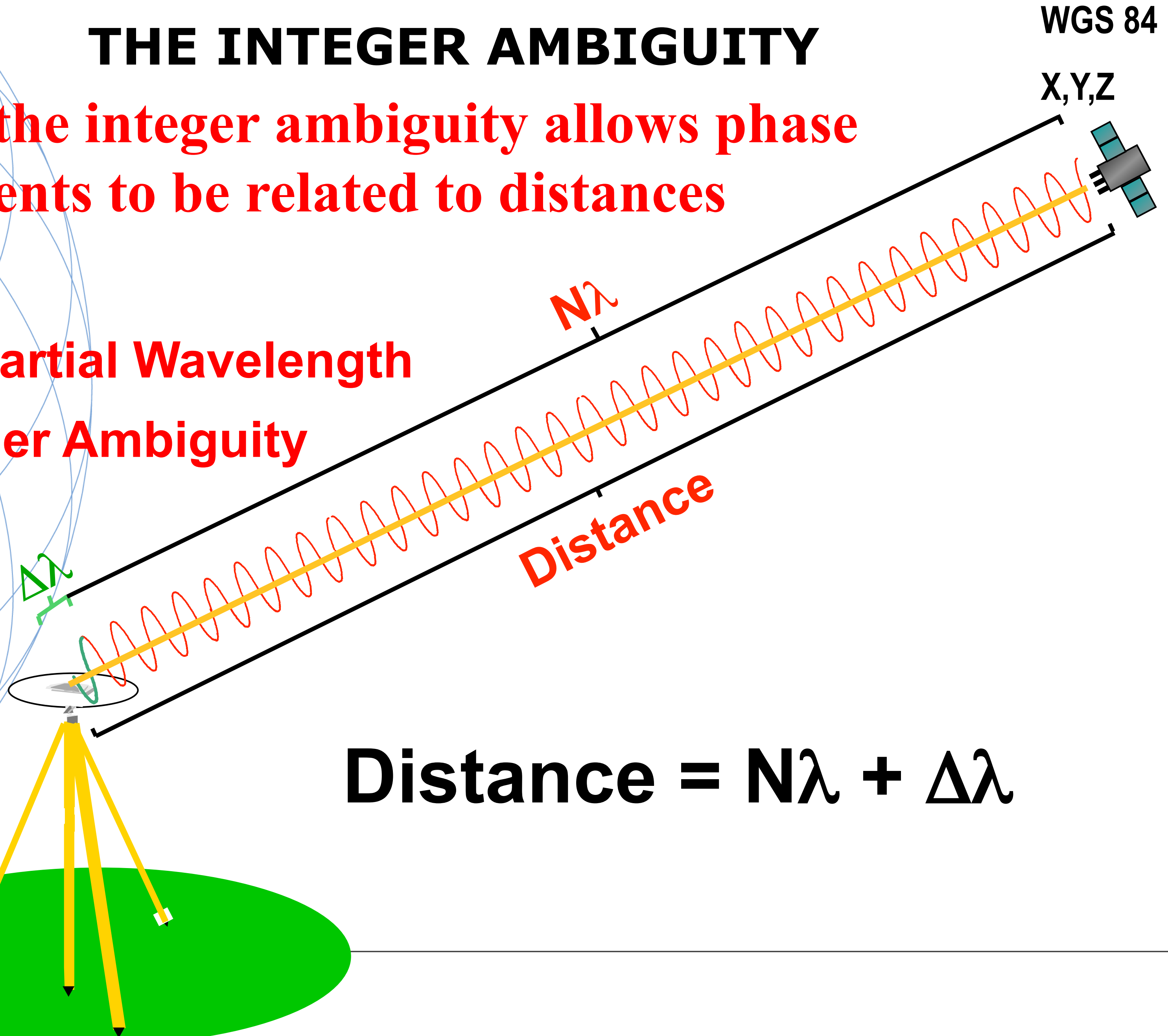
- Δ X,Y,Z FROM BASE FOR ROVER COORDINATES (REMEMBER "GIGO")
- ROVER CORRECTIONS FROM BASE
- MULTILATERATION - TIME (SEC.) ▪ ***C*** *(SPEED OF LIGHT)* (M/ SEC.*)*= *DISTANCE from satellite*
- MUST RESOLVE CARRIER CYCLE INTEGER COUNT AMBIGUITIES (# cycles ▪ wave length + partial cycle = distance)
- MUST 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

$\Delta\lambda$ = First Partial Wavelength

$N\lambda$ = Integer Ambiguity



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

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.

SOME REAL TIME INTEGER FIXING TECHNIQUES- DUAL FREQUENCY ALSO ENABLES OTF INITIALIZATION

- Wide Laning (L1 – L2) = **c** (speed of light) ÷ (1575.42 MHz – 1227.60 MHz) or 299,792.458 Km/sec ÷ 347.82 MHz = 0.862 m wave length.

- Narrow Laning
(L1 + L2) = **c** (speed of light) ÷ (1575.42 MHz + 1227.60 MHz) or 299,792.458 Km/sec ÷ 2803.02 MHz = 0.107 m wave length

- Iono Free $f(L_1)$ion-free = $a_1.f(L_1) + a_2.f(L_2)$

with $a_1 = f_1^2/(f_1^2 - f_2^2)$ and $a_2 = - f_1 \cdot f_2 /(f_1^2 - f_2^2)$

- Triple Differencing
- Kalman Filtering
- Double Differencing

THE CYCLE COUNT COOKBOOK- USING *DIFFERENCING* TO ELIMINATE OR REDUCE COMMON ERRORS IN THE RECEIVER AND SATELLITE (Alfred Leick via Peter Lazio)

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

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

ELIMINATED WITH DIFFERENCING

- IONO DELAY
- TROPO DELAY

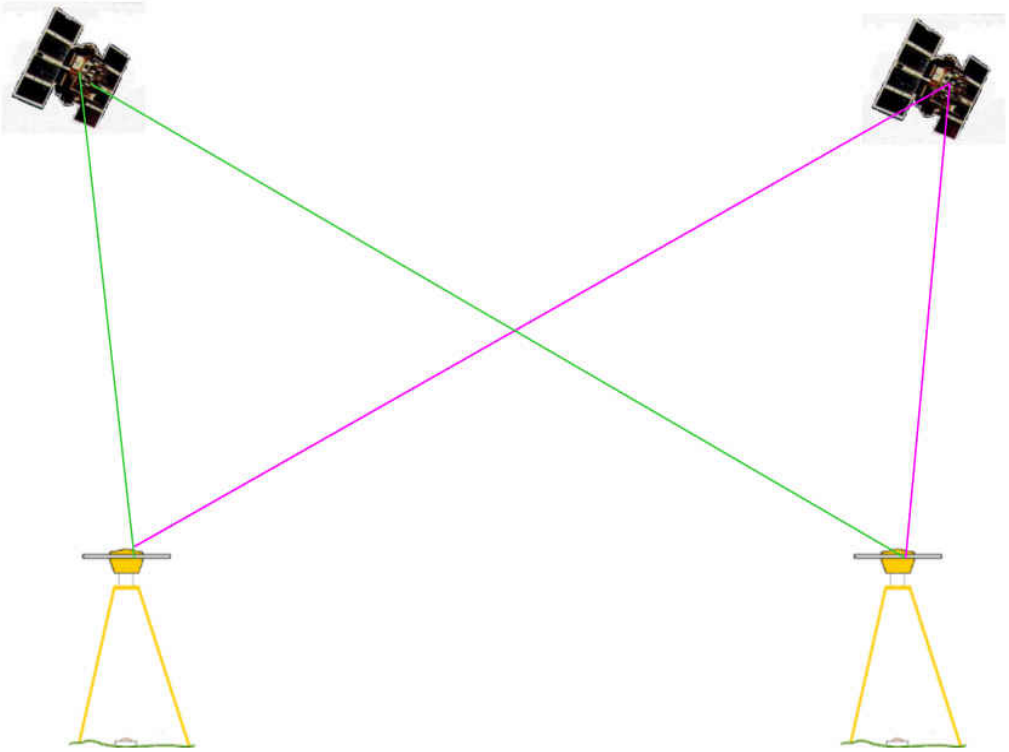
SAME AS BASE WITH SINGLE BASE INTERPOLATED WITH RTN

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

NOT ELIMINATED WITH DIFFERENCING

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.

DOUBLE DIFFERENCE

$\varphi_{km}^{pq}(t) = \varphi_{km}^{p}(t) - \varphi_{km}^{q}(t)$ is the **double difference** observable between SV p and q and Stations k and m at epoch t.

$$
\begin{aligned}
\varphi_{km}^{pq}(t) &= \varphi_{km}^{p}(t) - \varphi_{km}^{q}(t) \\
&= \frac{f}{c}\left(\rho_k^p(t) - \rho_m^p(t)\right) - f dt_{km}(t) + N_{km}^p - I_{km,\varphi}^p(t) + \frac{f}{c}T_{km}^p(t) + d_{km,\varphi}(t) + d_{km,\varphi}^p(t) + \varepsilon_{km,\varphi}^p \\
&\quad - \left(\frac{f}{c}\left(\rho_k^q(t) - \rho_m^q(t)\right) - f dt_{km}(t) + N_{km}^q - I_{km,\varphi}^q(t) + \frac{f}{c}T_{km}^q(t) + d_{km,\varphi}(t) + d_{km,\varphi}^q(t) + \varepsilon_{km,\varphi}^q\right) \\
&= \frac{f}{c}\left(\rho_k^p(t) - \rho_m^p(t) - \rho_k^q(t) + \rho_m^q(t)\right) - \left(\cancel{dt_{km}(t)} - \cancel{dt_{km}(t)}\right) + \left(N_{km}^p - N_{km}^q\right) - \left(I_{km,\varphi}^p(t) - I_{km,\varphi}^q(t)\right) \\
&\quad + \frac{f}{c}\left(T_{km}^p(t) - T_{km}^q(t)\right) + \left(\cancel{d_{km,\varphi}(t)} - \cancel{d_{km,\varphi}(t)}\right) + \left(d_{km,\varphi}^p(t) - d_{km,\varphi}^q(t)\right) + \left(\varepsilon_{km}^p - \varepsilon_{km}^q\right) \\
&= \frac{f}{c}\left(\rho_k^p(t) - \rho_m^p(t) - \rho_k^q(t) + \rho_m^q(t)\right) + N_{km}^{pq} - \left(I_{km,\varphi}^{pq}\right) + \frac{f}{c}\left(T_{km}^{pq}(t)\right) + d_{km,\varphi}^{pq}(t) + \varepsilon_{km}^{pq}
\end{aligned}
$$

Now the receiver clock errors and hardware delays cancel.

= difference between two single differences of two receivers and TWO satellites at the same epoch

RESULTING DIFFERENCED PHASE OBSERVABLE (CYCLES)

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

Superscripts refer to the satellite, subscripts refer to ground station

ASSUMED THE SAME FOR ROVER & BASE

OR MODELED BY RTN

LEAVES MULTIPATH, MEASUREMENT NOISE & RANGE TO SATELLITE

INTEGER SEARCH

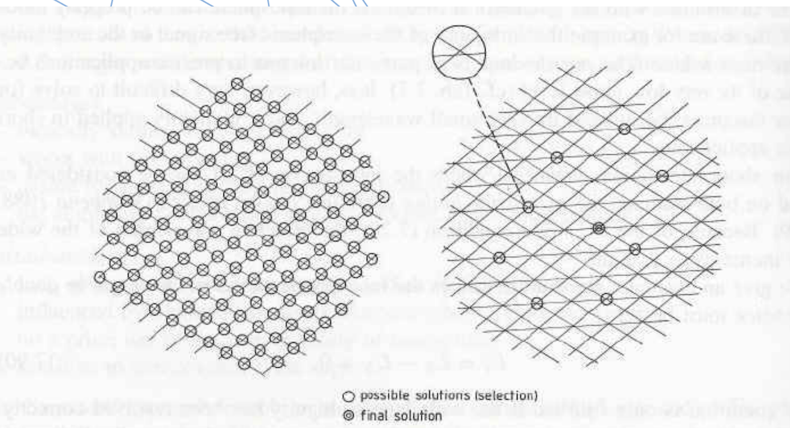


Fig. 7.36: Possible solutions for the ambiguities are selected; situation for two satellites (left) and three satellites (right)

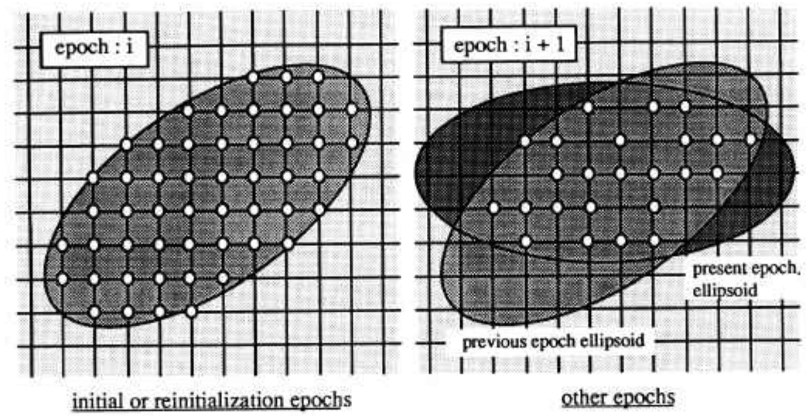


Figure 3.7. Two-dimensional perspective of constructing the mathematical searching spaces at various epochs.

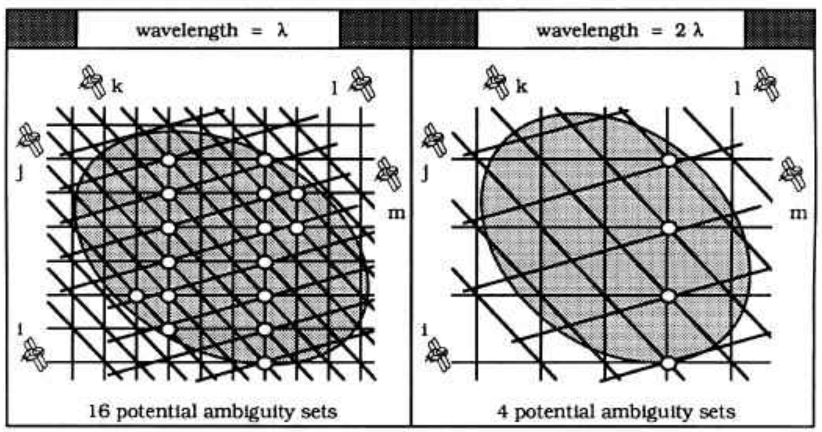


Figure 6.3. Two dimensional depiction of the impacts of the signal wavelength on the identification process of the correct ambiguities (5 satellites).

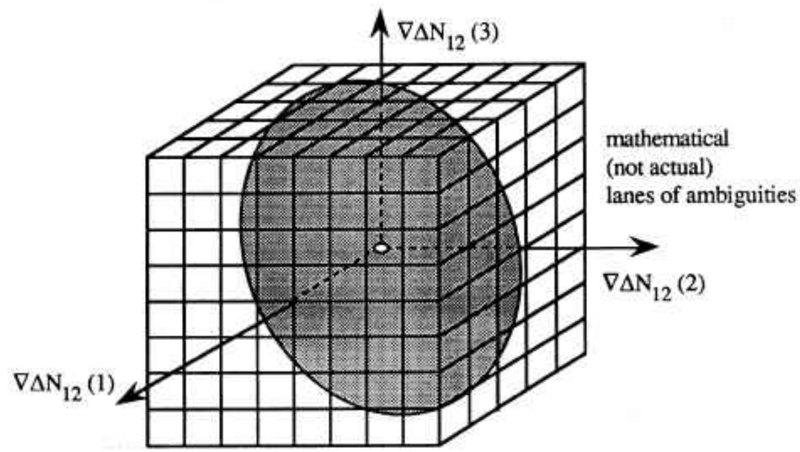
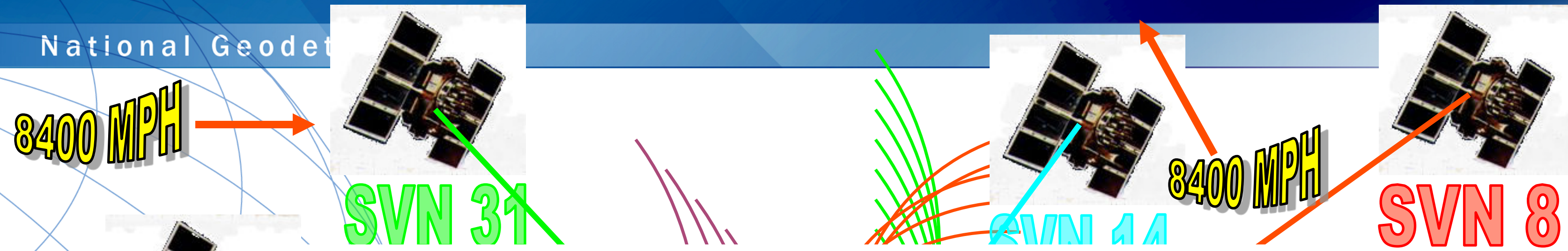
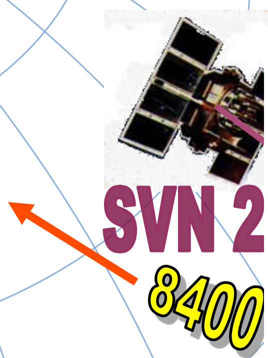
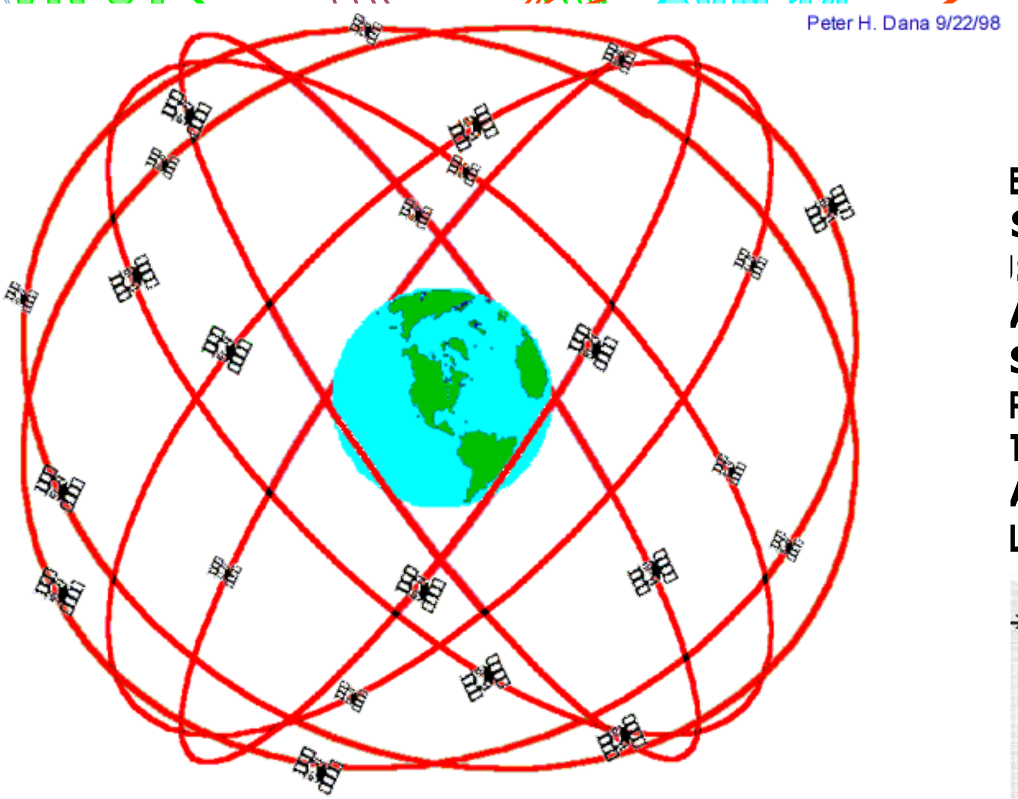


Figure 3.4. Cube and ellipsoidal ambiguity searching space.







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 ІST COMPUTE ANGE IN SITION DUE TO RTH ROTATION, TELLITE ORBIT ANGE AND LATIVITY!

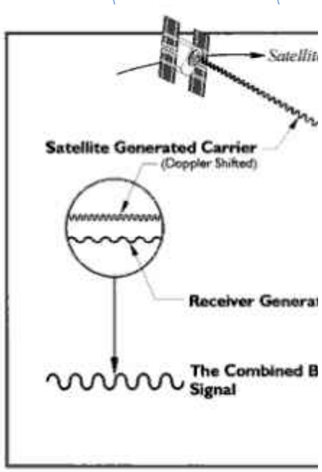
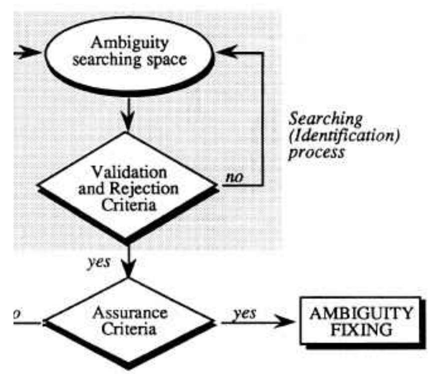


Figure 1.10. The Carrier Beat Phase.



eral strategy of on-the-fly ambiguity resolution.

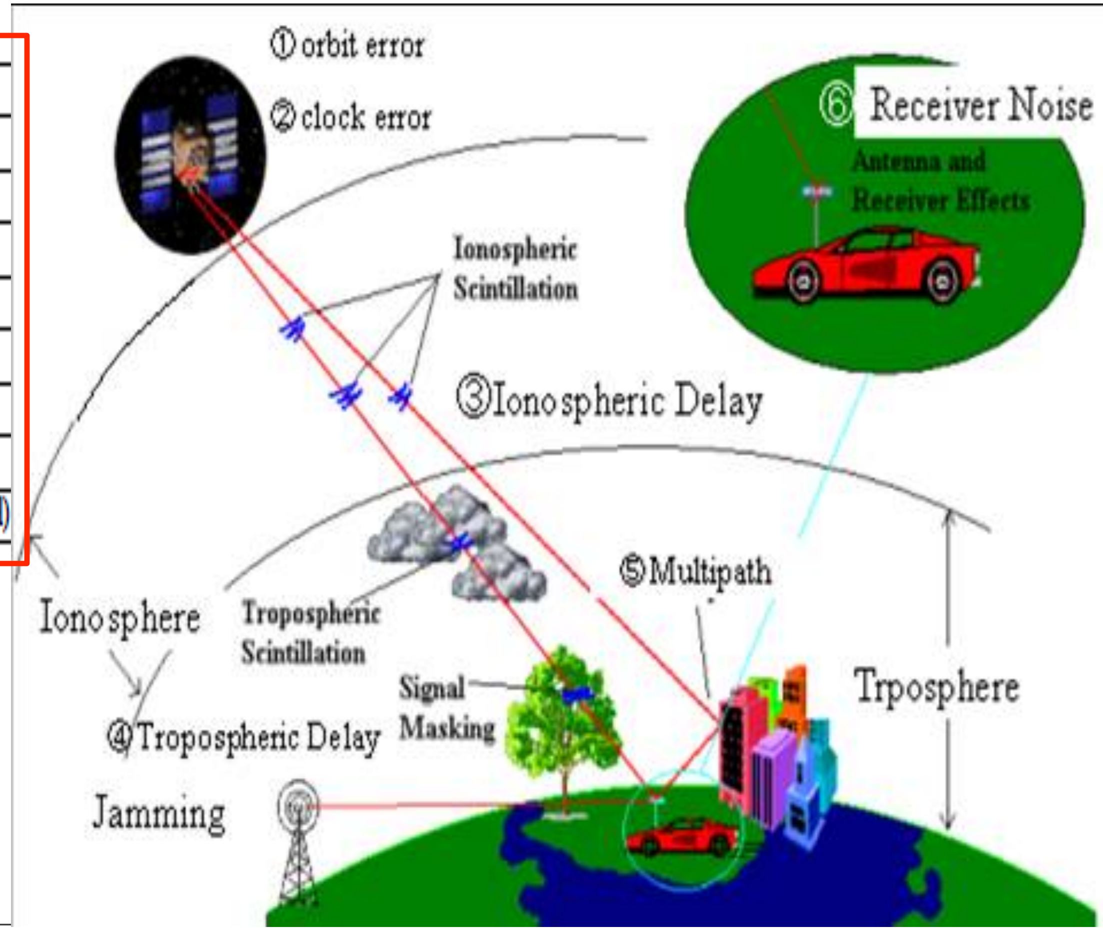
AT "C", 1 NANOSECOND = 30 CM!

WHAT AFFECTS RT PROCESSING?

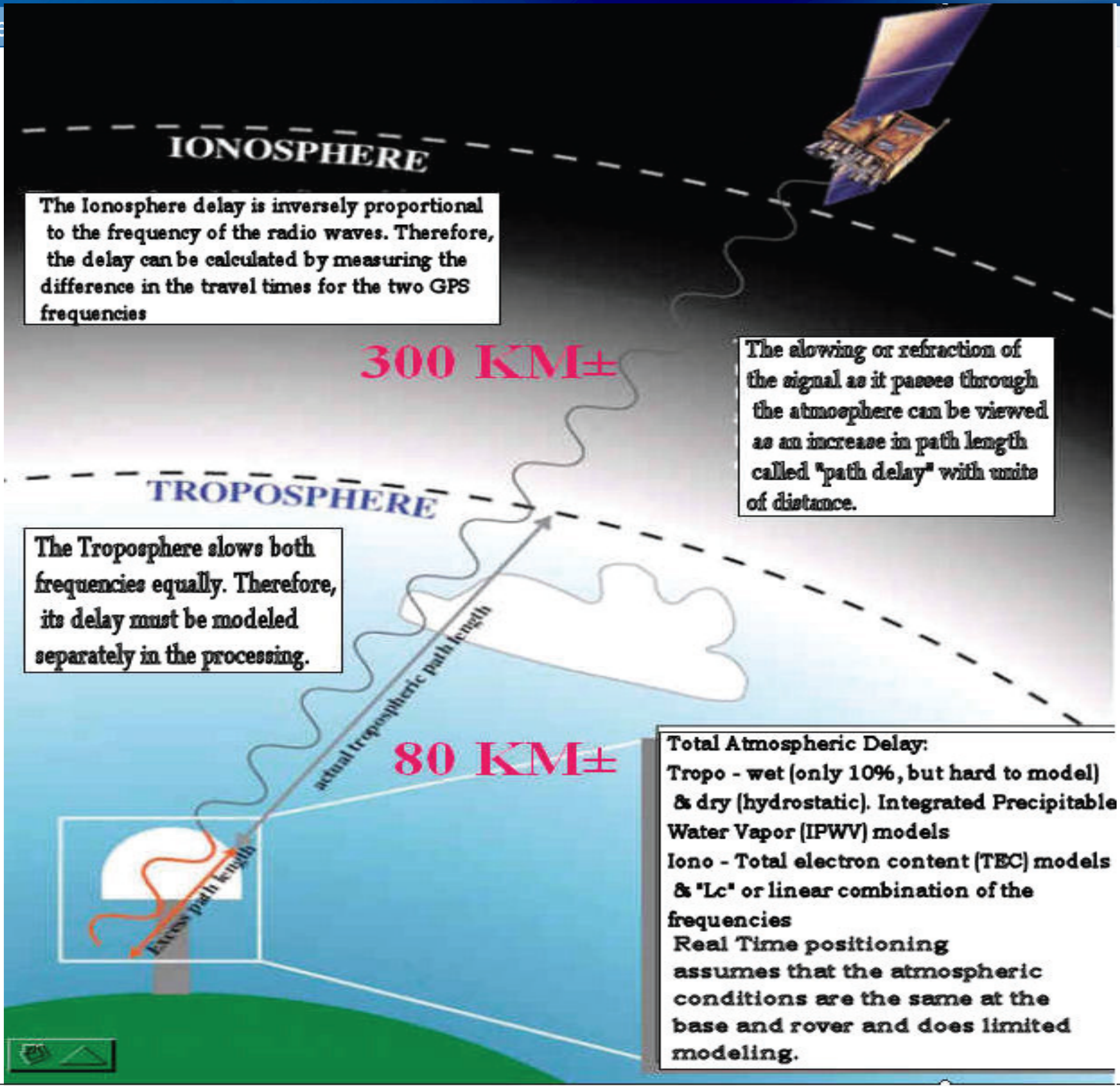
UNDIFFERENCED PHASE OBSERVABLE (CYCLES)

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

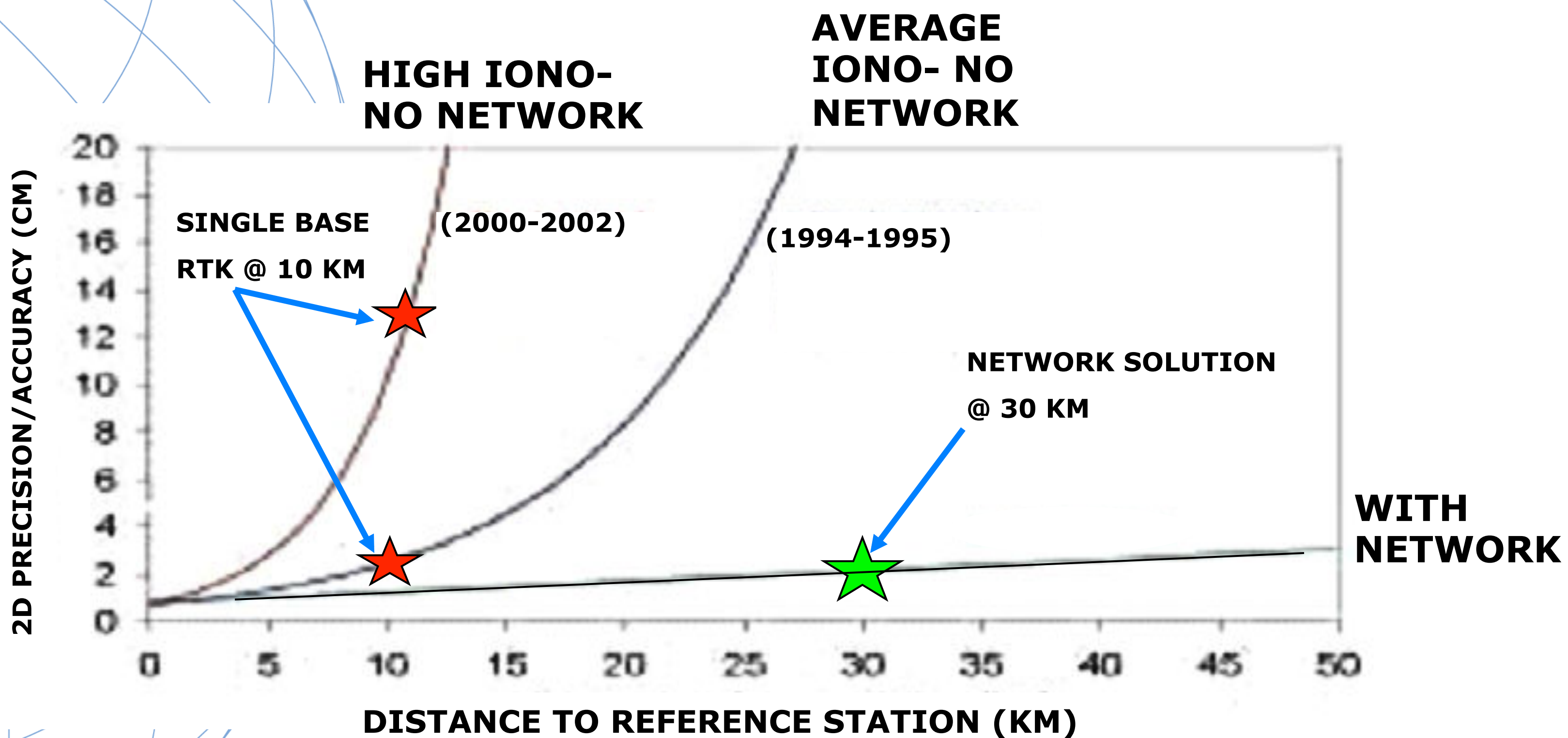
ERROR	VALUE
Ionosphere	4.0 METERS
Ephemeris	2.1 METERS
Clock	2.1 METERS
Troposphere	0.7 METERS
Receiver	0.5 METERS
Multipath	1.0 METERS
TOTAL	10.4 METERS
UNCORRELATEDERROR	5.15 m (square root of sum of errors squared)



IONO & TROPO LAYERS AND THEIR EFFECT ON THE GNSS SIGNAL- "DISPERSIVE" & "GEOMETRICAL" EFFECTS



IONOSPHERIC EFFECTS ON POSITIONING

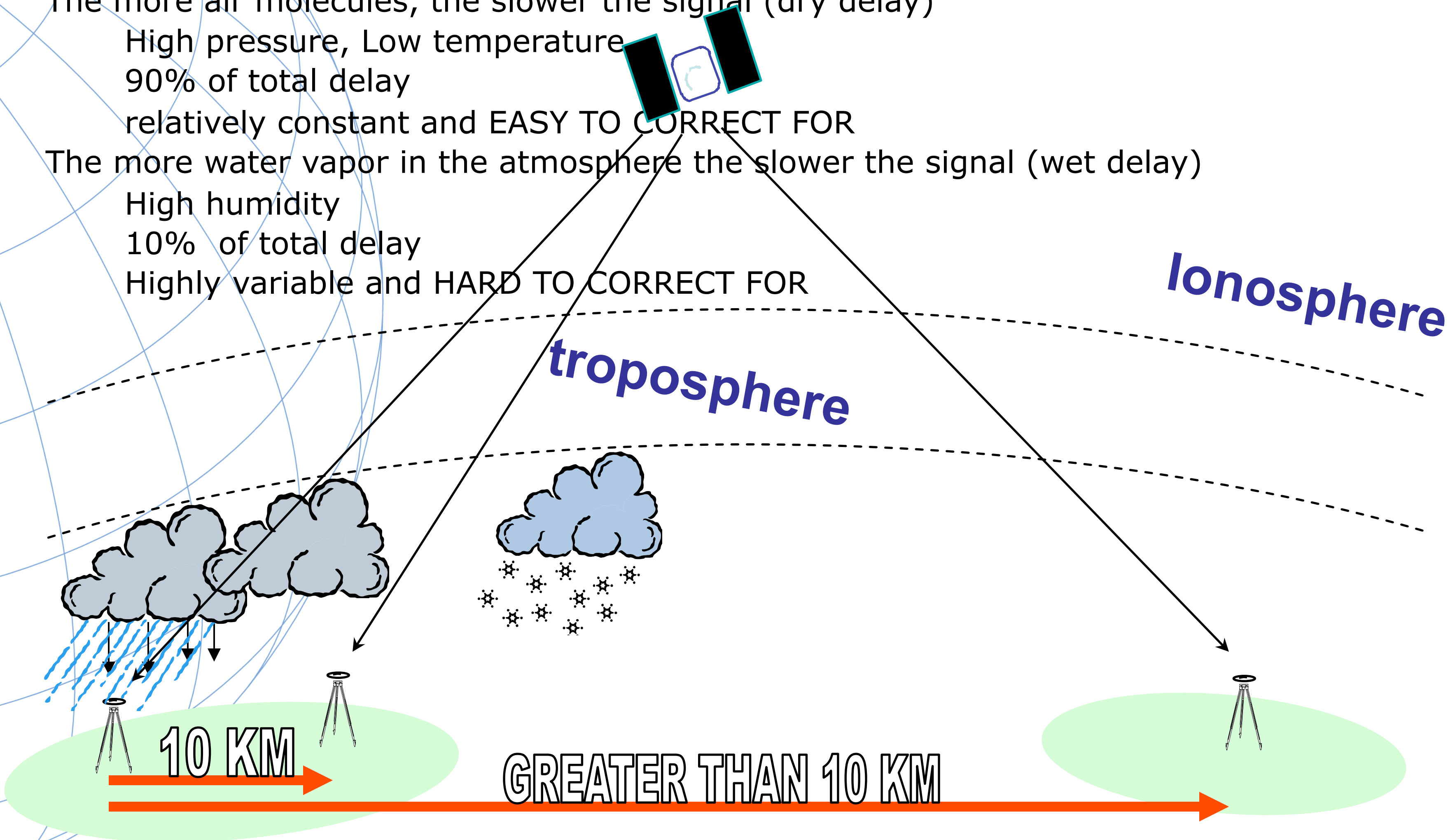


(SOURCE-BKG- GERMANY)

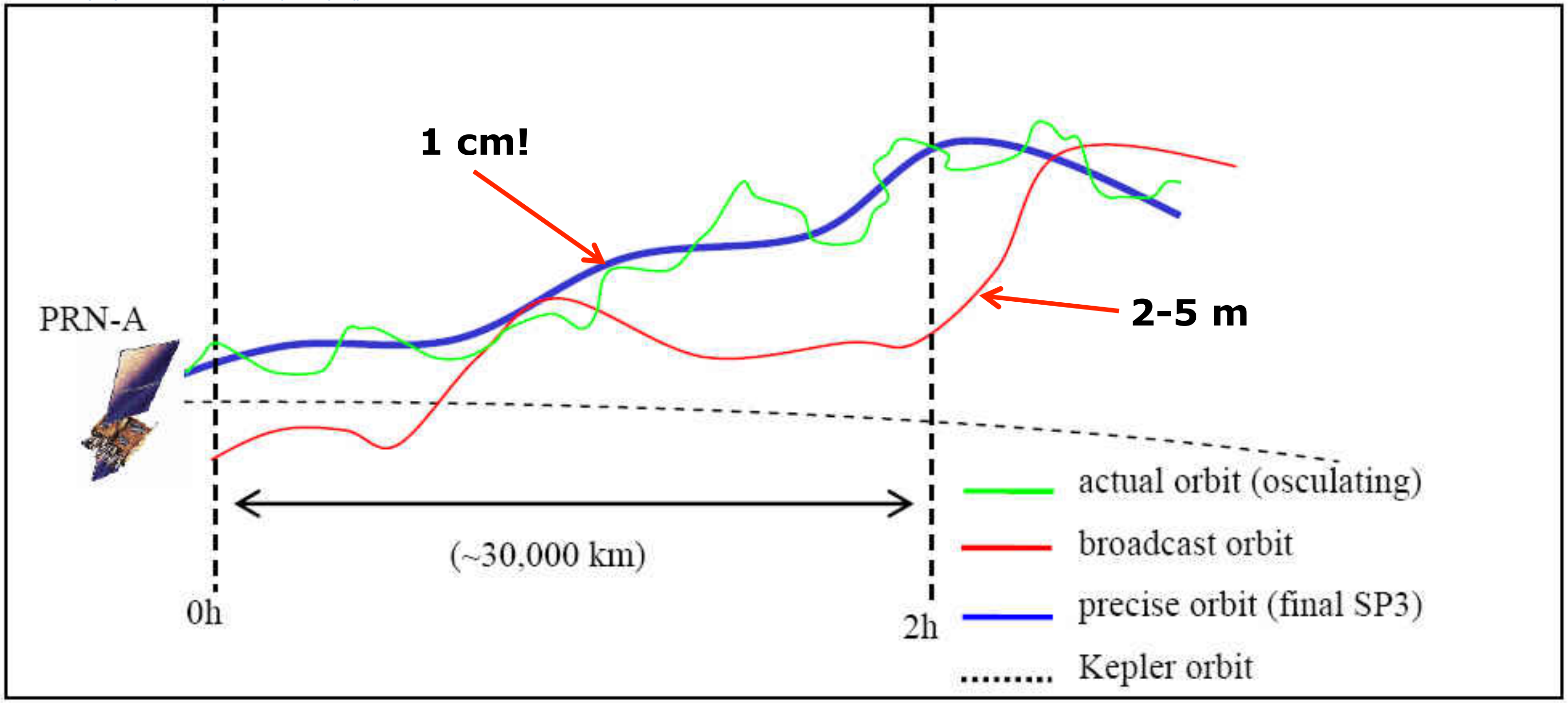
TROPOSPHERE DELAY

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



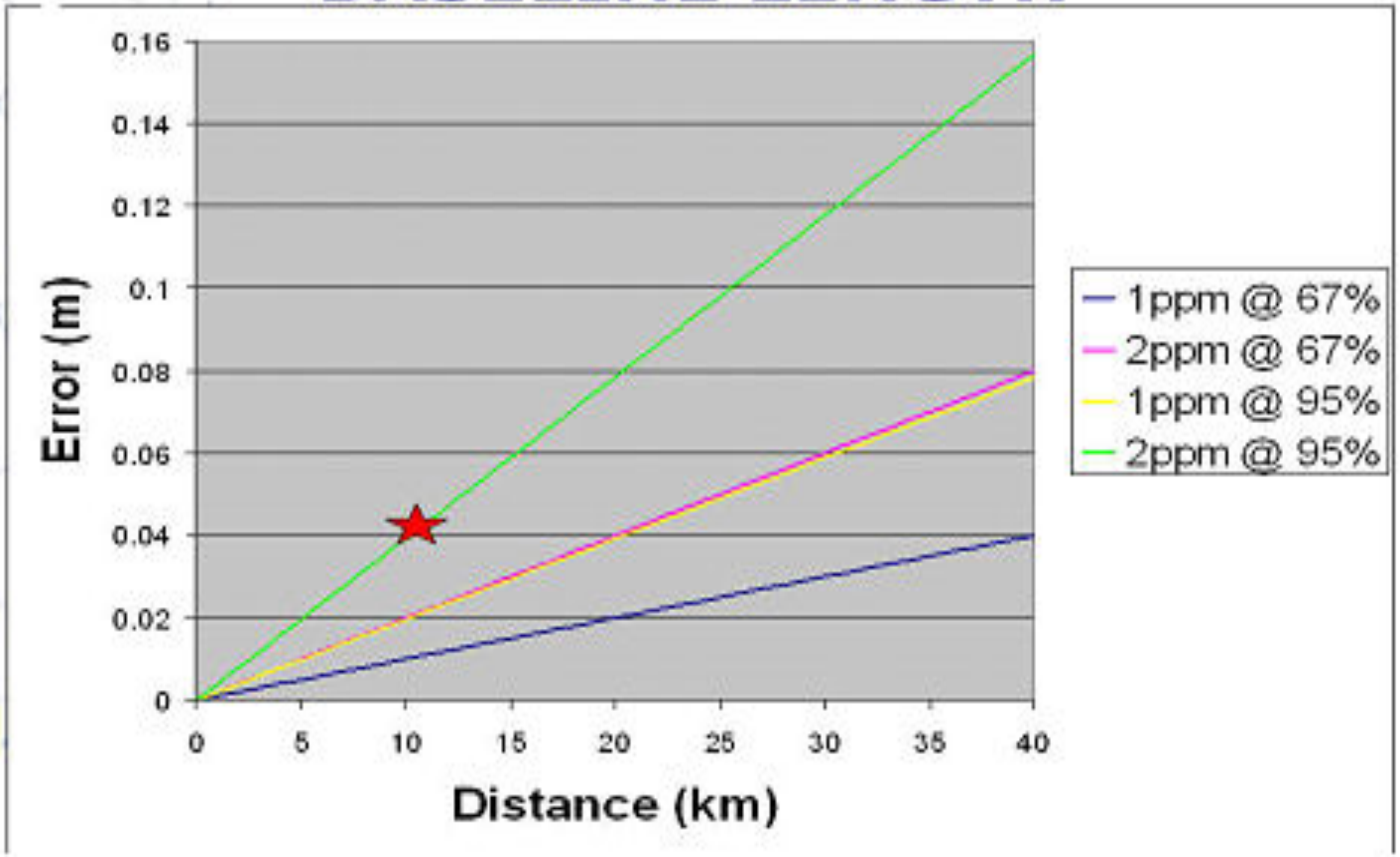
ORBITAL ERRORS CONTRIBUTING TO PPM ERRORS



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

IONO, TROPO, ORBIT CONTRIBUTE TO PPM ERROR

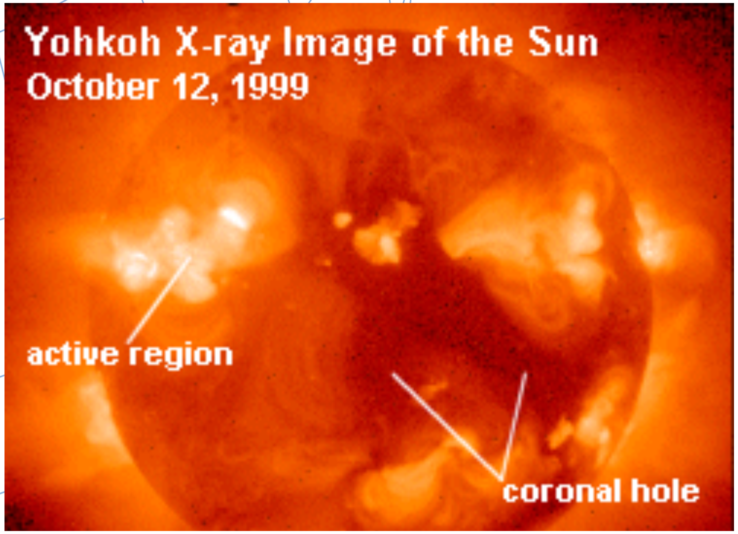
RTK PPM ERROR VS. BASELINE LENGTH

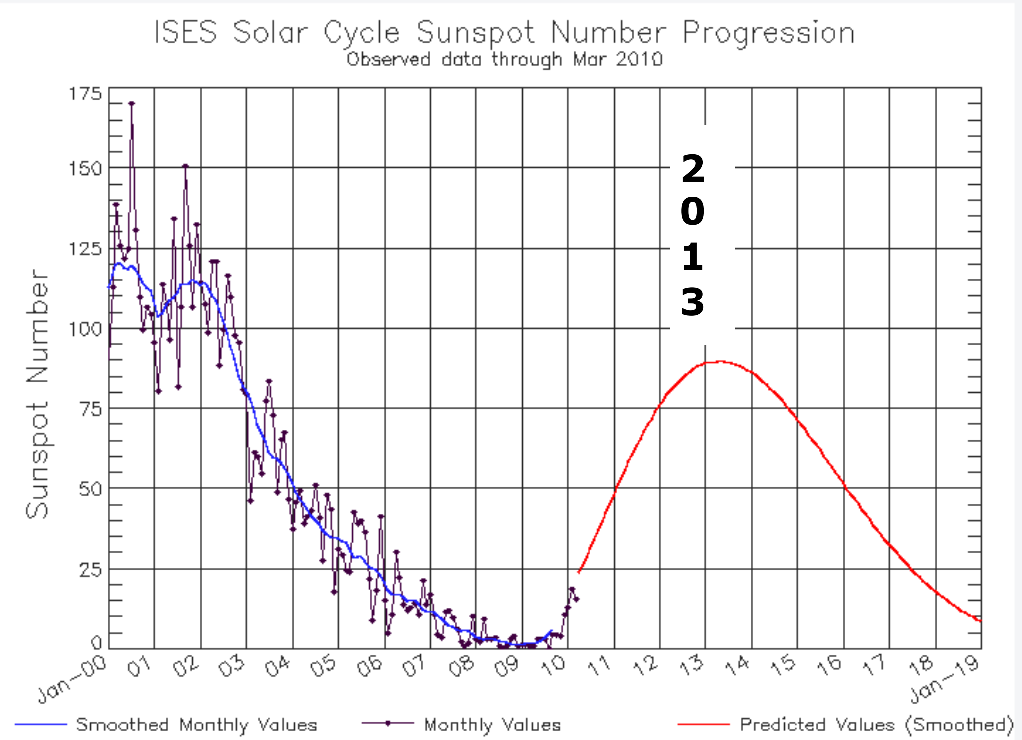


REMEMBER GNSS EQUIPMENT MANUFACTURERS' SPECS!

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





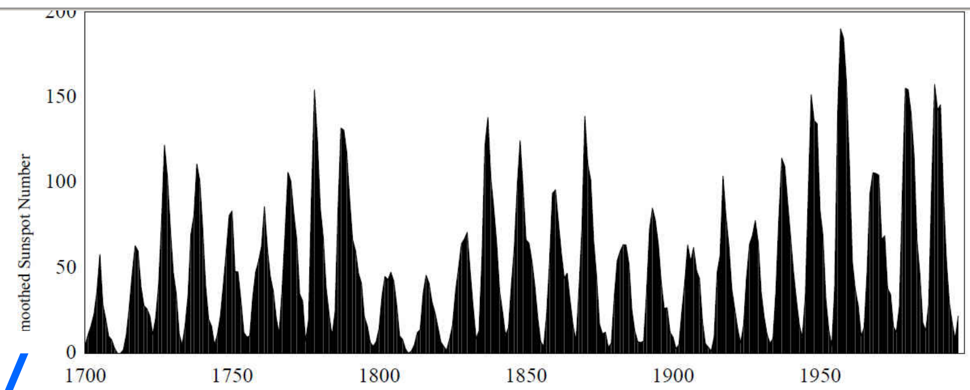
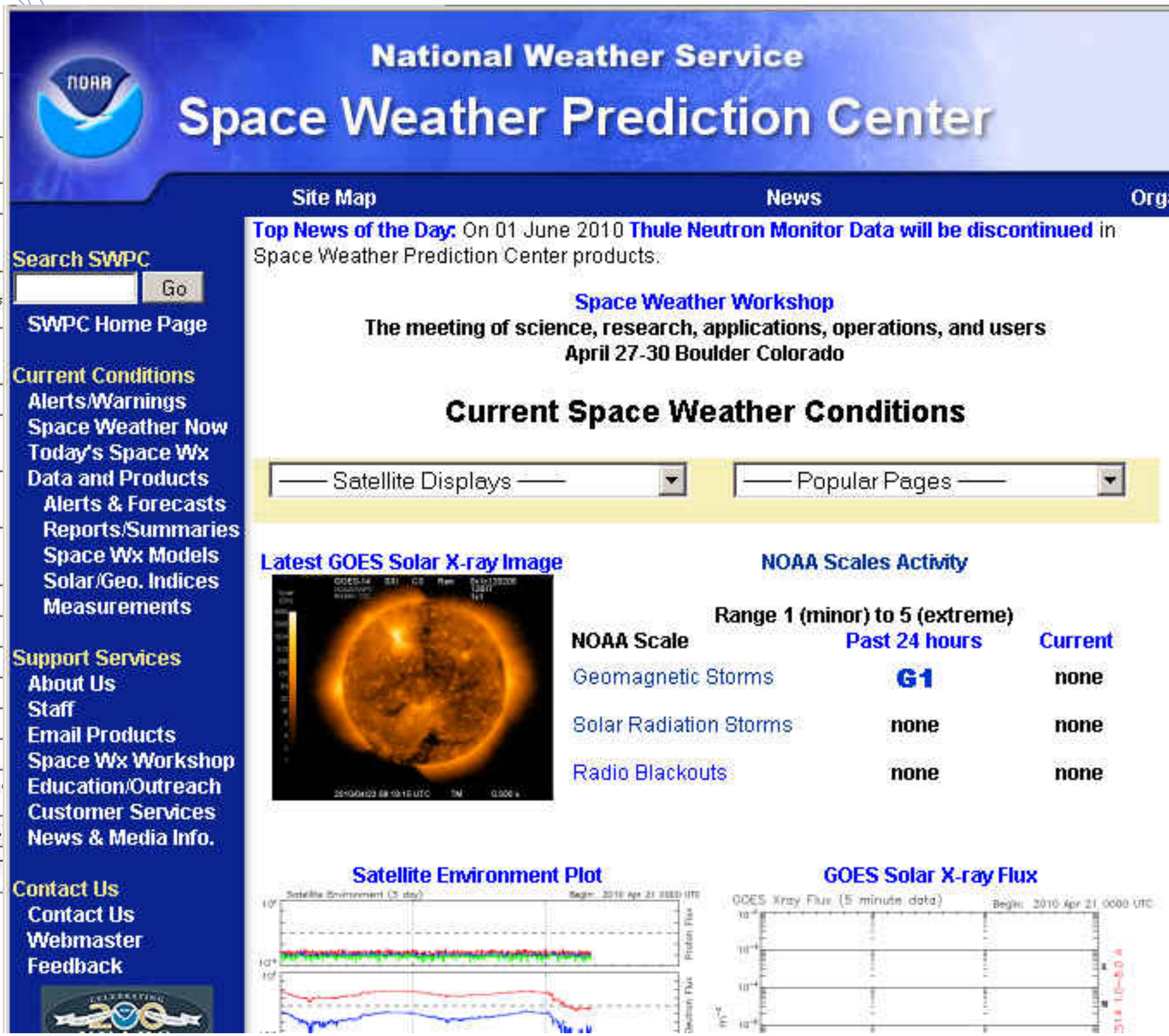


Figure 1. The Sunspot Cycle, well documented over the last 300 years, reveals a 10-11 year pattern of solar activity.

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

WWW.SWPC.NOAA.GOV

	Solar Radio Interference
Satellite operations	
Monitoring orbital variation	
Monitoring command & control anomalies	x
Ground-to-spacecraft communications	x
Aviation:	
Middle-latitude communication (VHF)	x
Polar-cap communication (HF)	
Navigation (VLF)	
High-altitude polar flights	
Electric Power Distribution	
Long-line telephone communications	
HF communication	
Pipeline operations	
Geophysical exploration	
Scientific satellite studies - Shuttle, Spacelab, s interplanetary missions	
Scientific rocket studies - Sun, magnetosphere,	
Scientific ground studies - Sun, interplanetary m seismological, biological	



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
```

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

```
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.
```

BIG PICTURE ISSUES IN RT POSITIONING

- ★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

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

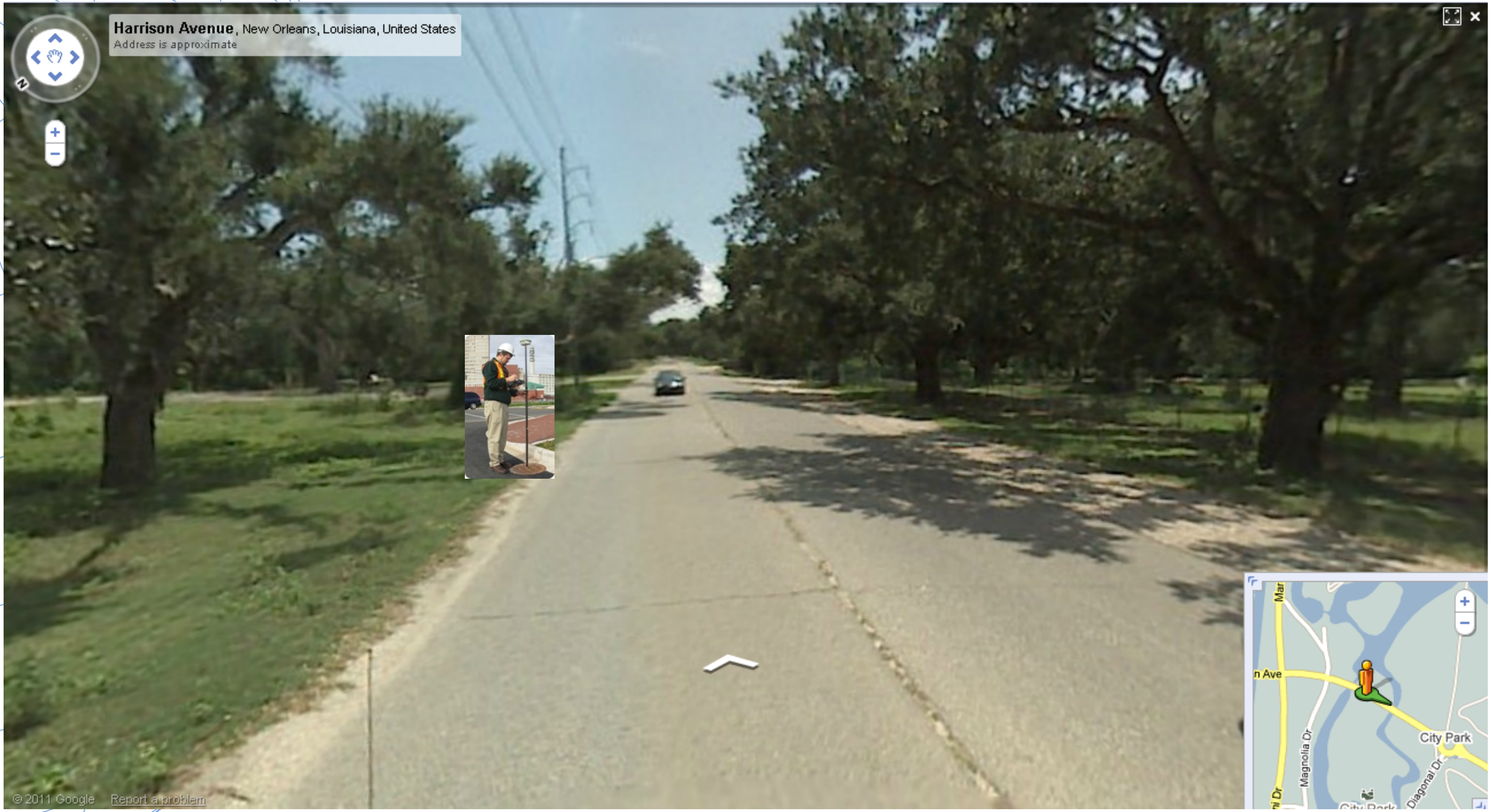
(Can't initialize with only GLN Sats.)

BEST SCENARIO = 7 OR MORE GPS

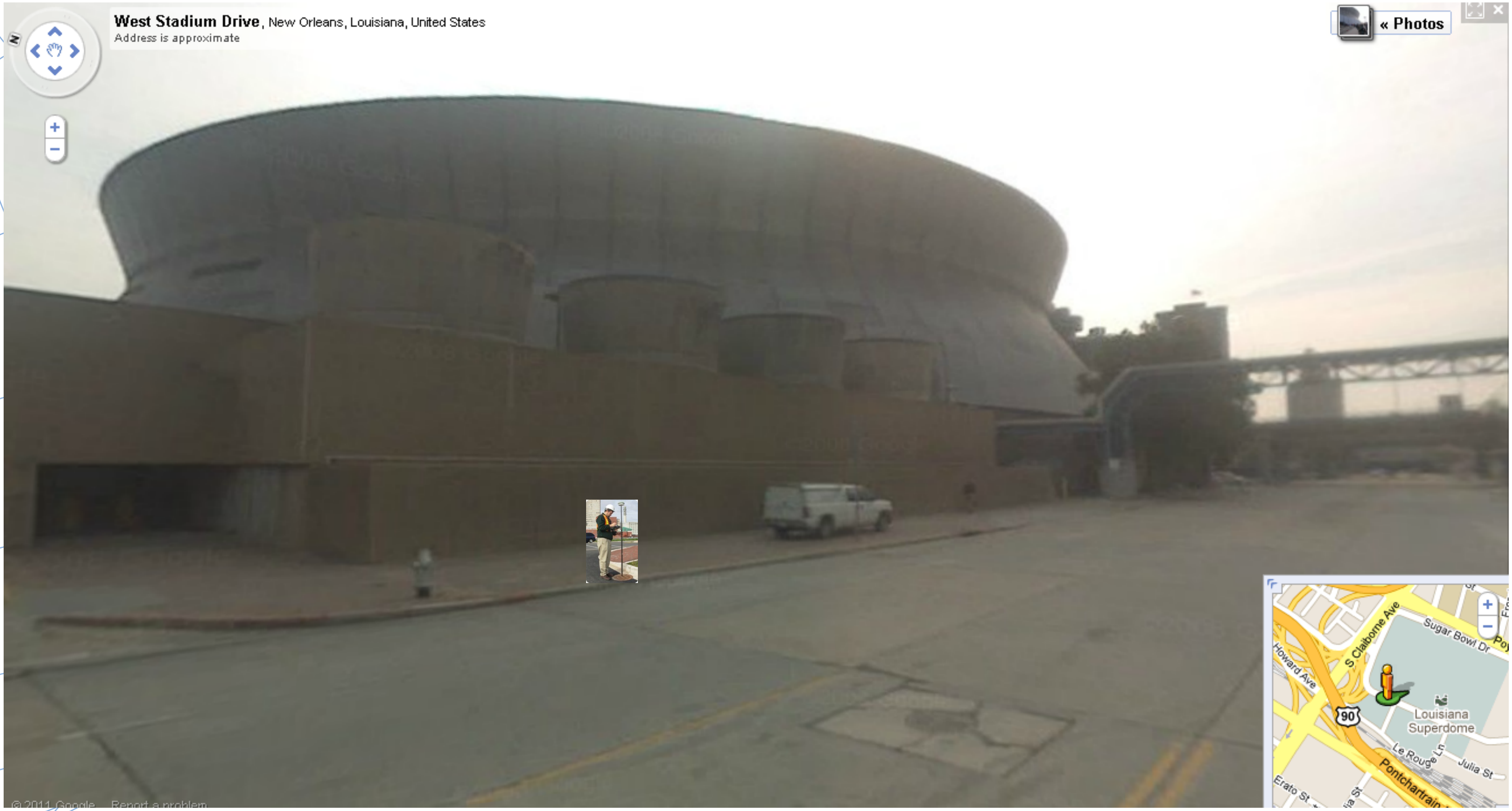
GLN "K" SATS WILL HAVE A CDMA (L3) FORMAT SIGNAL

GNSS CAN HELP IN URBAN CANYONS

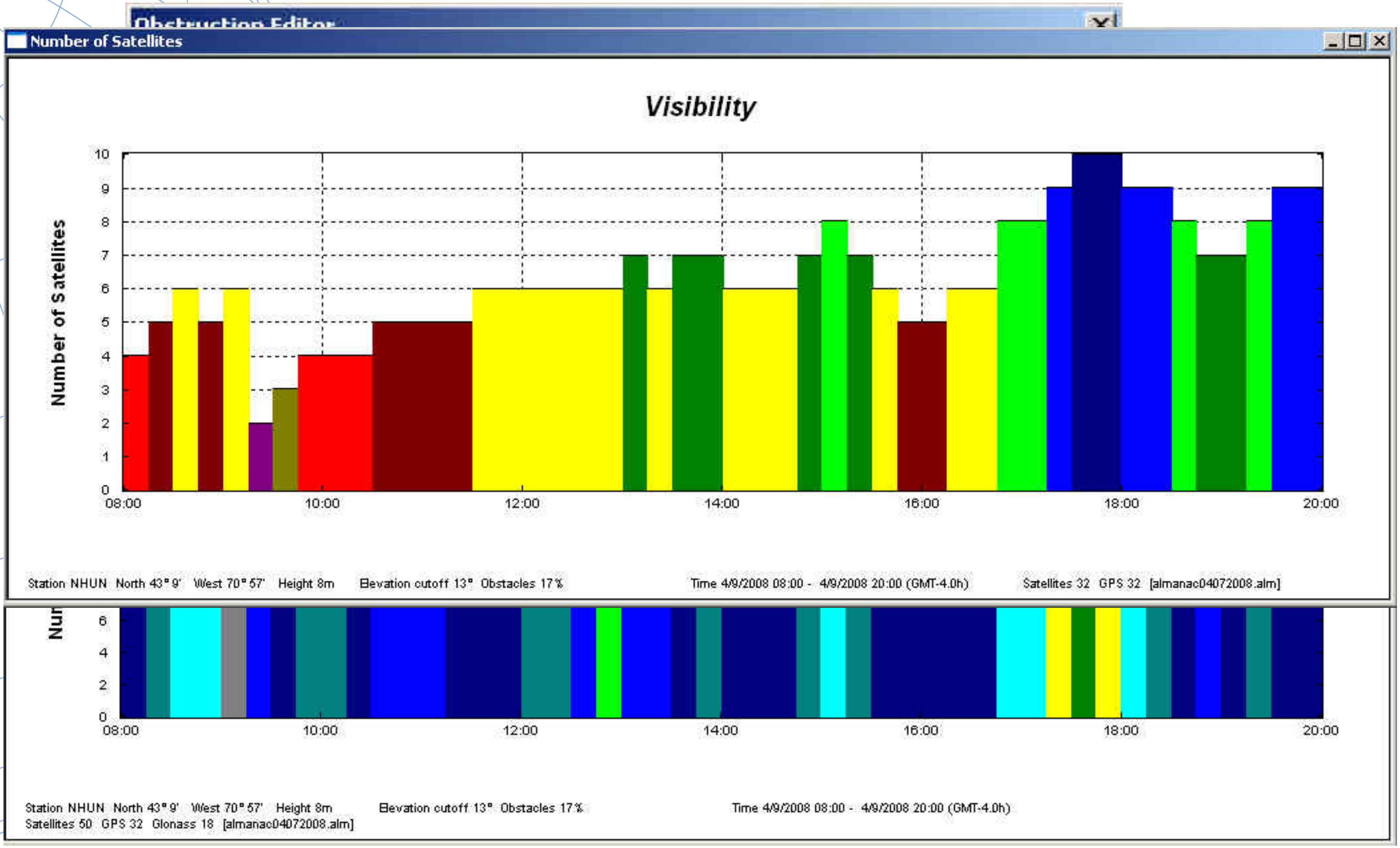
GNSS CAN HELP IN CORRIDOR SURVEYS



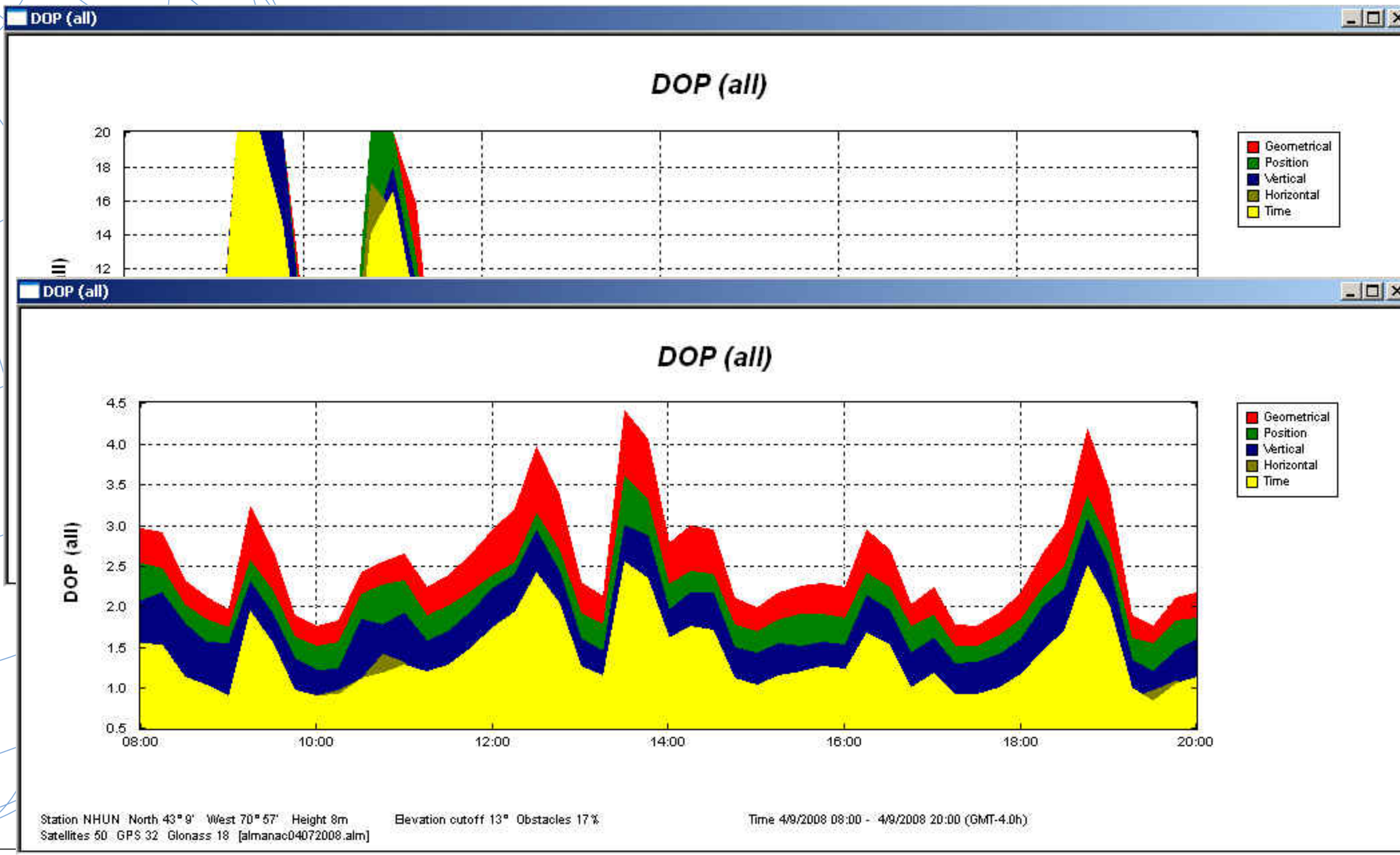
GNSS CAN HELP IN OBSTRUCTED AREAS



NHUN – SATELLITES/ WITH OBSTRUCTIONS



NHUN – DOP / WITH OBSTRUCTIONS



"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, no multipath

FOR RTN LOOK FOR:
GDOP ≤ 3 (or PDOP ≤ 2.5)
Number of GPS satellites ≥7
Time on point = 5 second record intervals for 1 minute
Position RMS ≤ 0.02 m horizontal, 0.04 vertical (ellipsoidal).
Redundancy ≥ 2 locations staggered by 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

- **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.

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)

-

LightSquared

- LightSquared, formerly known as SkyTerra and Mobile Satellite Ventures (MSV), is based in Reston, Virginia.

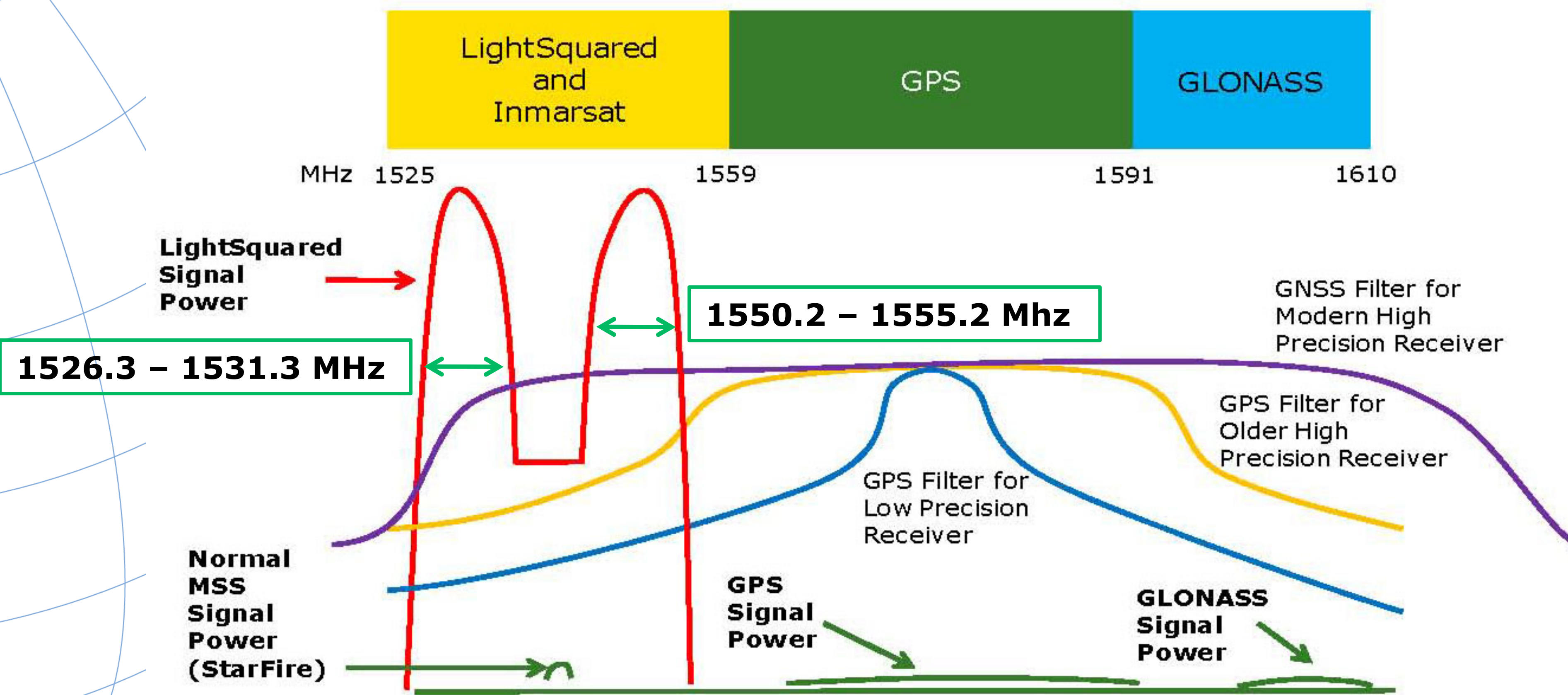
- LightSquared is deploying an open wireless $14 billion broadband communications system with uplink (base station to handset) signals operating in the 1525-1559 MHz frequency band.

- LightSquared plans to provide coverage to the entire United States by deploying more than 40,000 ATC base stations by 2015.

- Recently, the Federal Communications Commission (FCC) conditionally approved an application for a waiver allowing LightSquared to repurpose the satellite spectrum immediately neighboring Global Positioning System (GPS) for use ground-based transmissions via Ancillary Terrestrial Component (ATC).

- NPEF findings- interference to all users

PROPOSED L1 BAND ALLOCATIONS FOR LIGHTSQUARED



LightSquared Interference to GPS and StarFire
17 March 2011
JOHN DEERE

THE LIGHT SQUARED ISSUE-
COALITION TO SAVE OUR GPS

Webinar: 4/27/2011

http://www.saveourgps.org/

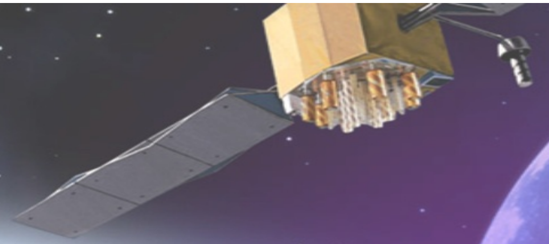
Jim Kirkland, VP and General Counsel of Trimble Navigation
and
Nick Yaksich, VP, Global Public Policy at the Association of Equipment Manufacturers

GPS is deeply embedded in the aviation, electrical power, financial, and cell phone industries. There are more than 1 billion GPS receivers worldwide. And there are more than 2,500 GPS-based Wide Area Augmentation System (WAAS) approaches in the U.S. Further, the Federal Aviation Administration's NextGen air traffic control (ATC) concept depends on GPS.

LIGHT SQUARE REPORT SUBMITTAL DATE EXTENDED 2 WEEKS (FROM JUNE 15)

THE LIGHT SQUARED ISSUE

The Facts



If the issue had been settled in 2002, LightSquared wouldn't have sought this unusual waiver in the first place.

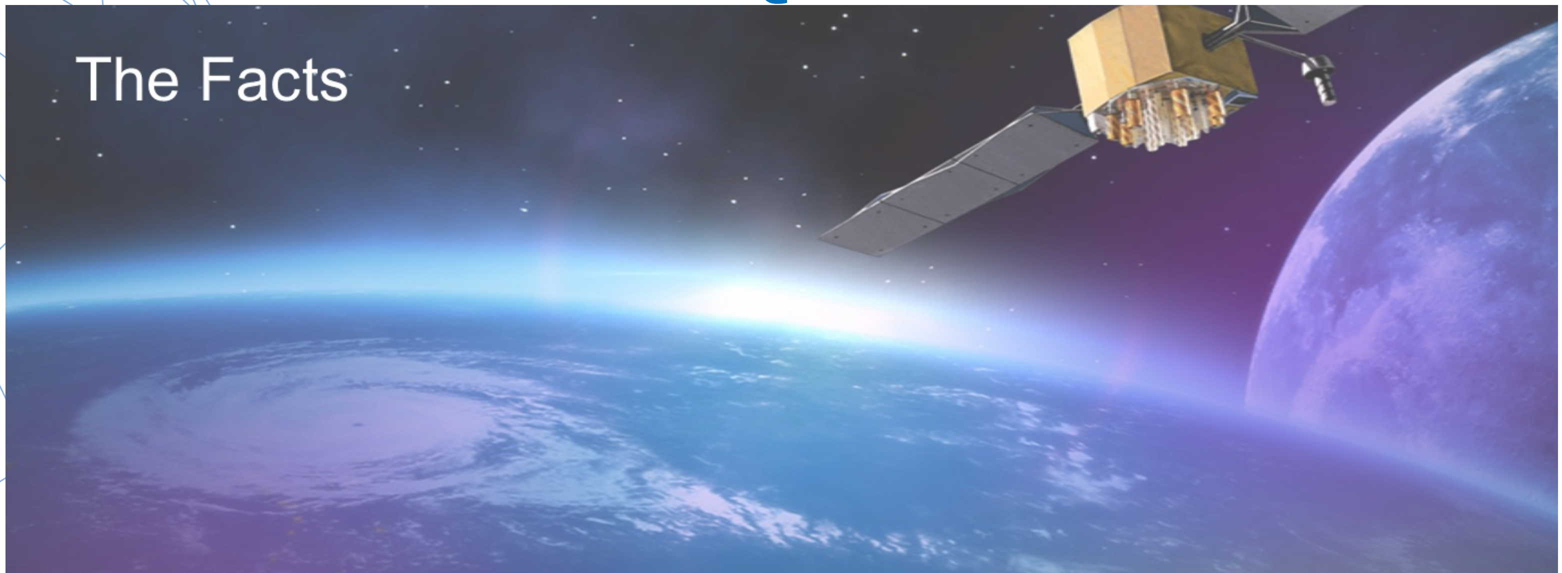
The 2002/2003 agreements were made to enable 'Mobile Satellite Ventures,' now known as 'LightSquared,' to have a limited number of low-powered ground stations only to fill in coverage gaps in a satellite service. The proposal at the time was limited to a total of 2,415 stations in the U.S. with power limited to just 26 watts of power toward the horizon. Contrast that with the entirely new proposal of 40,000 stations licensed for up to 1,500 watts of power, and that's why this matter is only now an issue.

There is no GPS receiver problem. The problem was created when a hedge fund investor decided to repurpose spectrum immediately adjacent to GPS for a use that is dramatically different from the minimal ground-based use previously permitted by FCC rules - and, by every indication to date, is incompatible with existing GPS uses.

https://www.saveourgps.org

THE LIGHT SQUARED ISSUE

The Facts

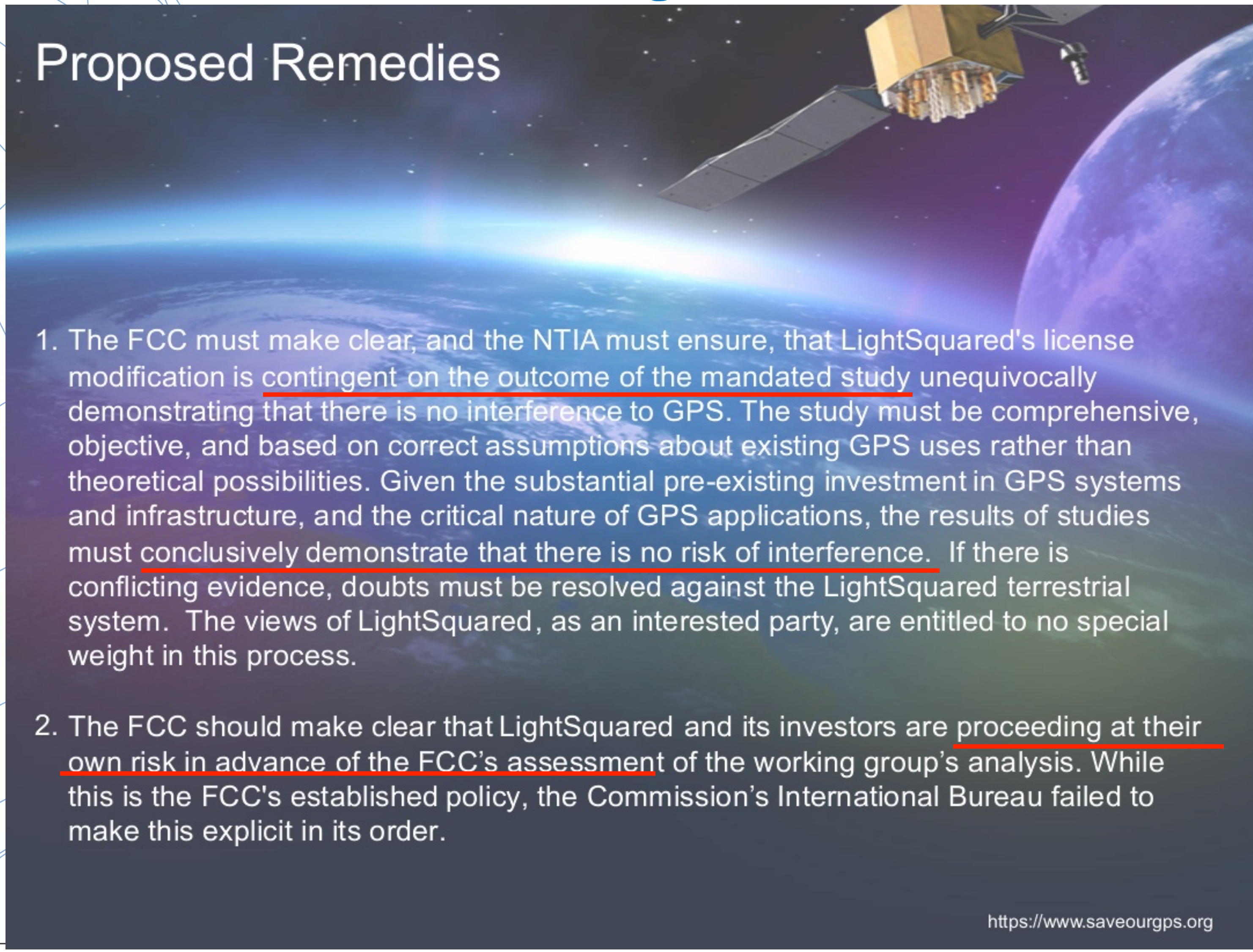


This is not an engineering problem, but one of physics. GPS receivers use high-quality filters that can resist adjacent signals hundreds of thousands of times the power of the GPS signal. But the laws of physics can overwhelm those filters when the signal is billions of times more powerful and right next door. It has yet to be proven that any practical filter could block adjacent signals billions of times more powerful.

Those who contend that this is a GPS problem are manipulating or simply ignoring the facts and are flat out wrong. The GPS signals, powered by solar panels, are so faint and LightSquared's ground station signals are so powerful that no existing filter can overcome this physics problem.

https://www.saveourgps.org

THE LIGHT SQUARED ISSUE



THE LIGHT SQUARED ISSUE

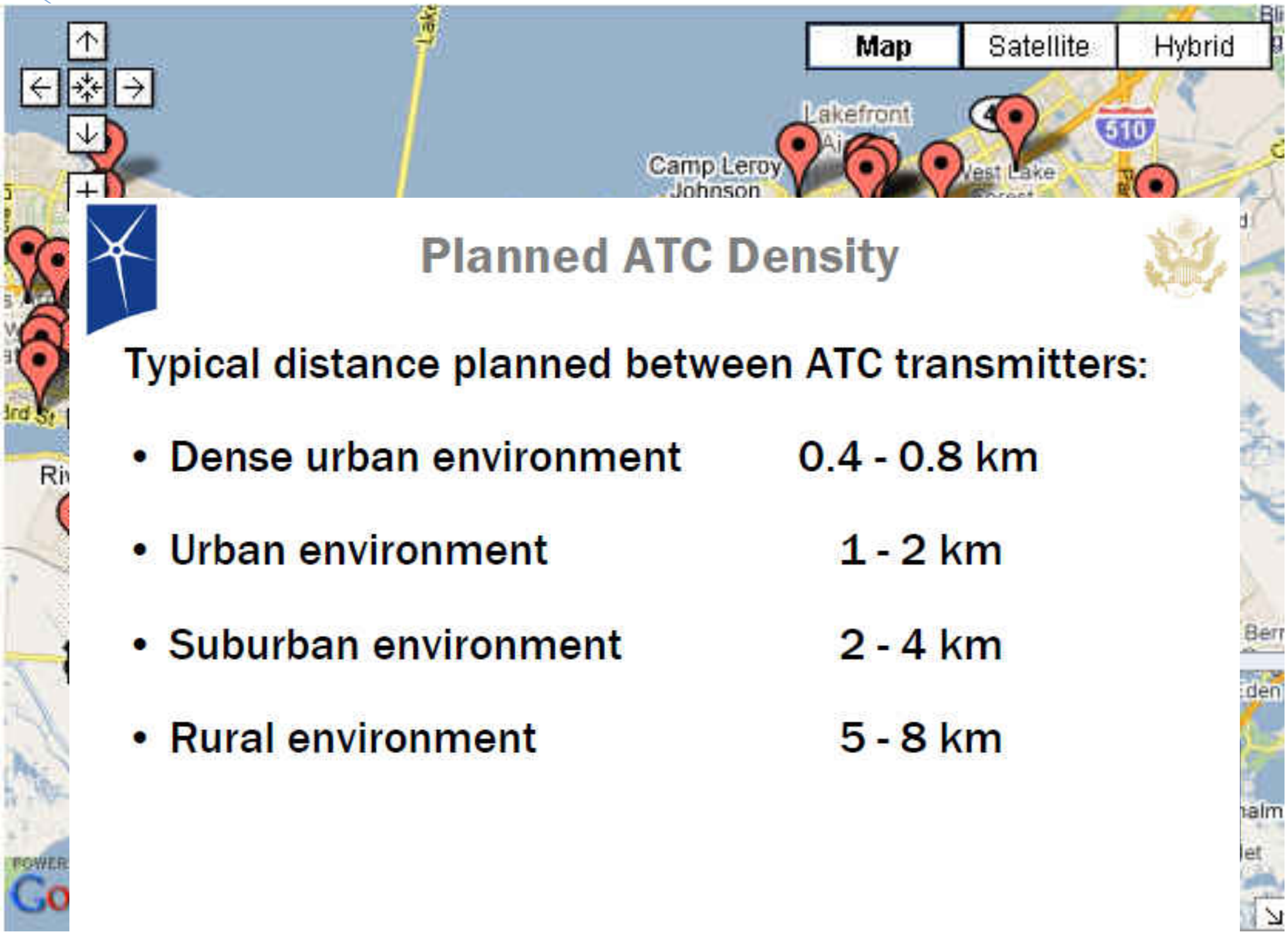
Proposed Remedies (cont.)

3. Resolution of interference has to be the obligation of LightSquared, not the extensive GPS user community of millions of citizens. LightSquared must bear the costs of preventing interference emanating from their devices, and if there is no way to prevent interference, it should not be permitted to operate. GPS users or providers should not have to bear any of the consequences of LightSquared's actions.

4. This is a matter of critical national interest. There must be a reasonable opportunity for public comment of at least 45 days on the report produced by the working group and further FCC actions on the LightSquared modification order should take place with the approval of a majority of the commissioners, not at the bureau level.

https://www.saveourgps.org

CELL TOWER COVERAGE IN NEW ORLEANS



Planned ATC Density

Typical distance planned between ATC transmitters:

- Dense urban environment 0.4 - 0.8 km
- Urban environment 1 - 2 km
- Suburban environment 2 - 4 km
- Rural environment 5 - 8 km

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?

Appendix C

Adjusting the Circular Level Vial

From SECO (http://www.surveying.com/tech_tips/details.asp?techTipNo=13):

ADJUSTMENT OF THE CIRCULAR VIAL:

1. Set up and center bubble as precisely as possible.

2. Rotate center pole 180 degrees. If any part of the bubble goes out of the black circle adjustment is necessary.

3. Move quick release legs until bubble is half way between position one and position two.

4. With a 2.5 mm allen wrench turn adjusting screws until bubble is centered. Recommended procedure is to tighten the screw that is most in line with the bubble. Caution: very small movements work best.

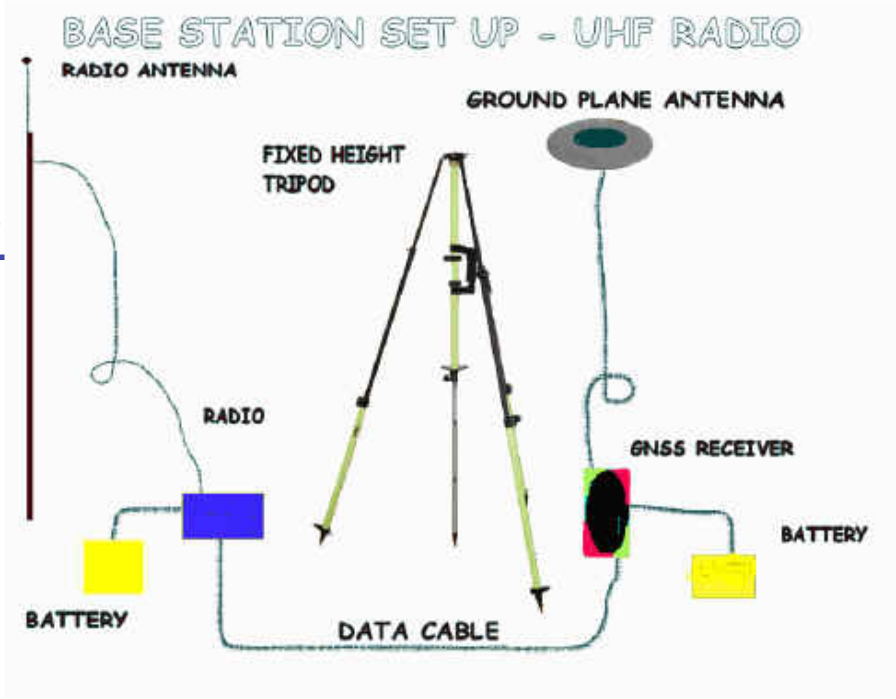
5. Repeat until bubble stays entirely within circle.

A rover pole with an adjusted **standard 40 minute vial** located about midpoint of the length should introduce a maximum leveling error of no more than 2.5 mm (less than 0.01 feet). It should be noted that 10 minute vials are available.

Diagram II-1 - Typical circular vial assembly for the Rover pole

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 ≥ 5, GLN = 0
GPS = 4, GLN = 2
GPS = 3, GLN = 3
GPS = 2, GLN = 4
(Can't initialize with only GLN Sats.)

Dilution Of Precision - DOP

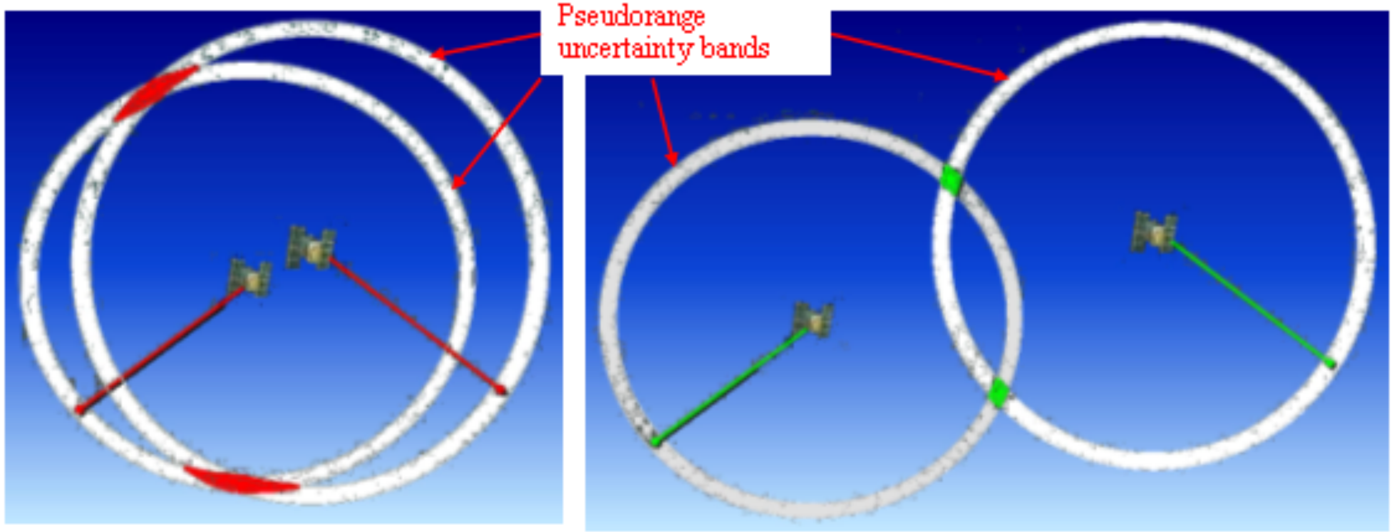


Diagram II-2 — Diagram II-3

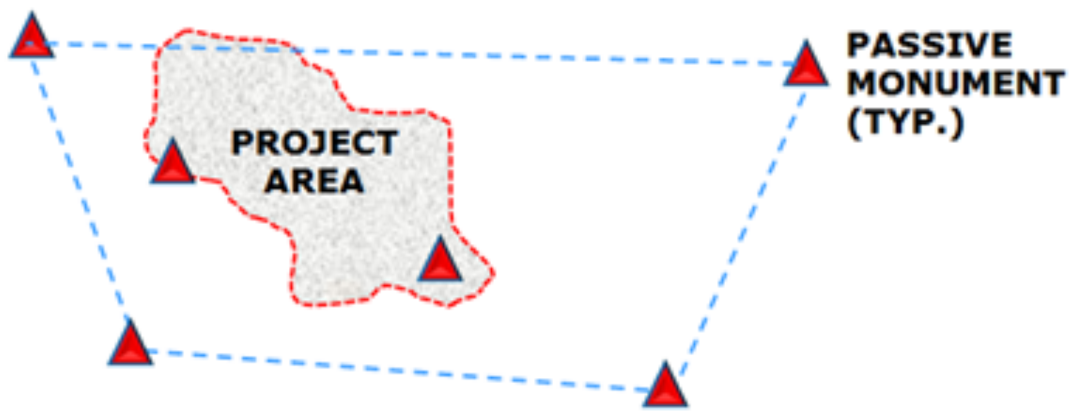
High PDOP- Satellites Close Together — Low PDOP – Satellites Spread.

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.

CONSTRAINTS (OR NOT)

- B ≥ 4 H & V, KNOWN & TRUSTED POINTS?
- B LOCALIZATION RESIDUALS-OUTLIERS?
- B DO ANY PASSIVE MARKS NEED TO BE

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



RT DERIVED ORTHO HEIGHTS - LOCALIZE OR NOT?

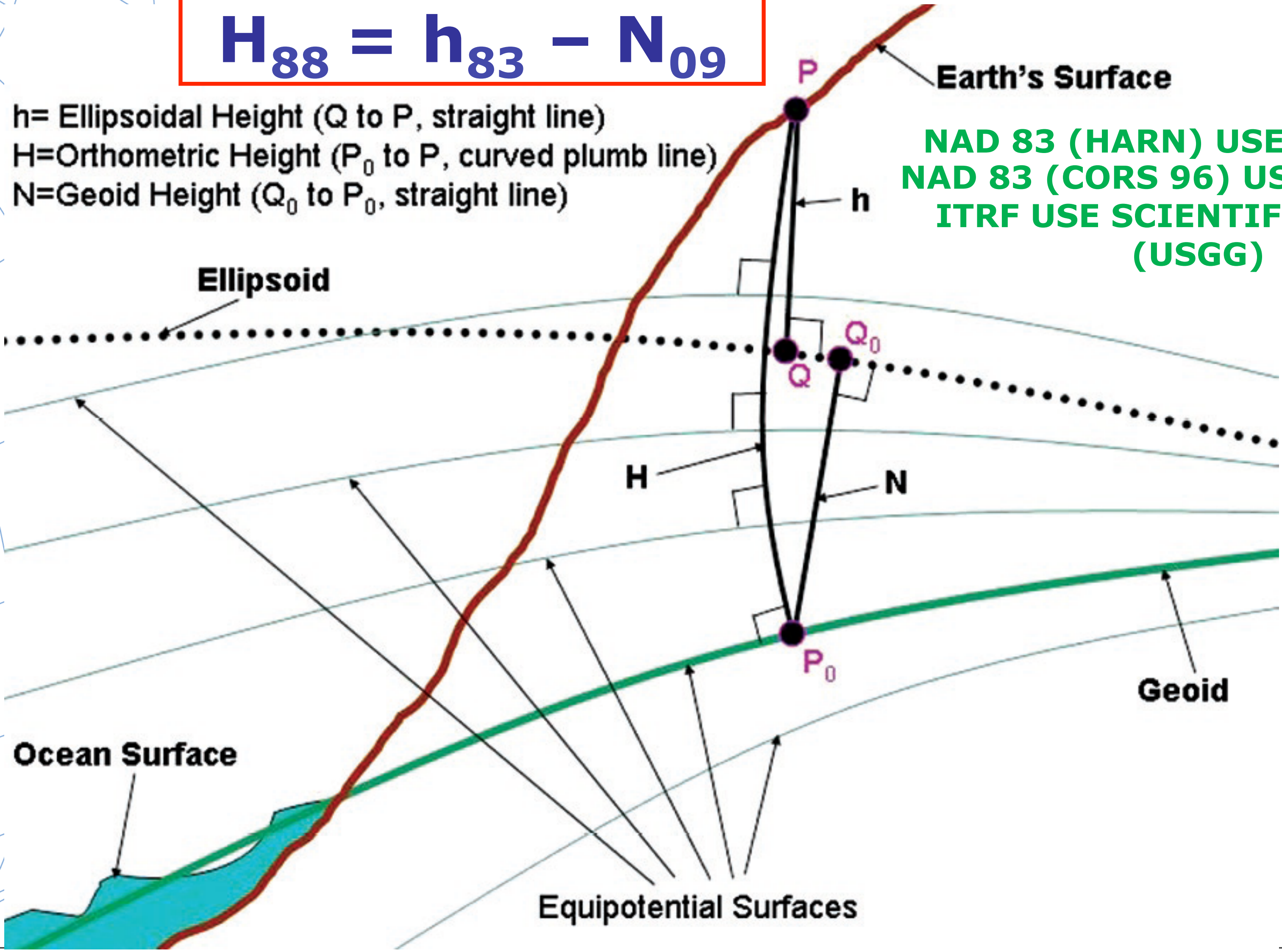
- PASSIVE MARKS ARE A SNAP SHOT OF WHEN THEY WERE LEVELED OR DERIVED FROM GPS
- IF YOU BUILD FROM A MONUMENTED BM AND THE DESIGN WAS DONE REFERENCED TO IT, IT IS "THE TRUTH", UNLESS IN GROSS ERROR.
- CONSTRAINING TO PASSIVE BMs IS A GOOD WAY TO NOT ONLY LOCK TO THE SURROUNDING PASSIVE MARKS, BUT ALSO 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)

ELLIPSOID, GEOID & ORTHO HEIGHTS

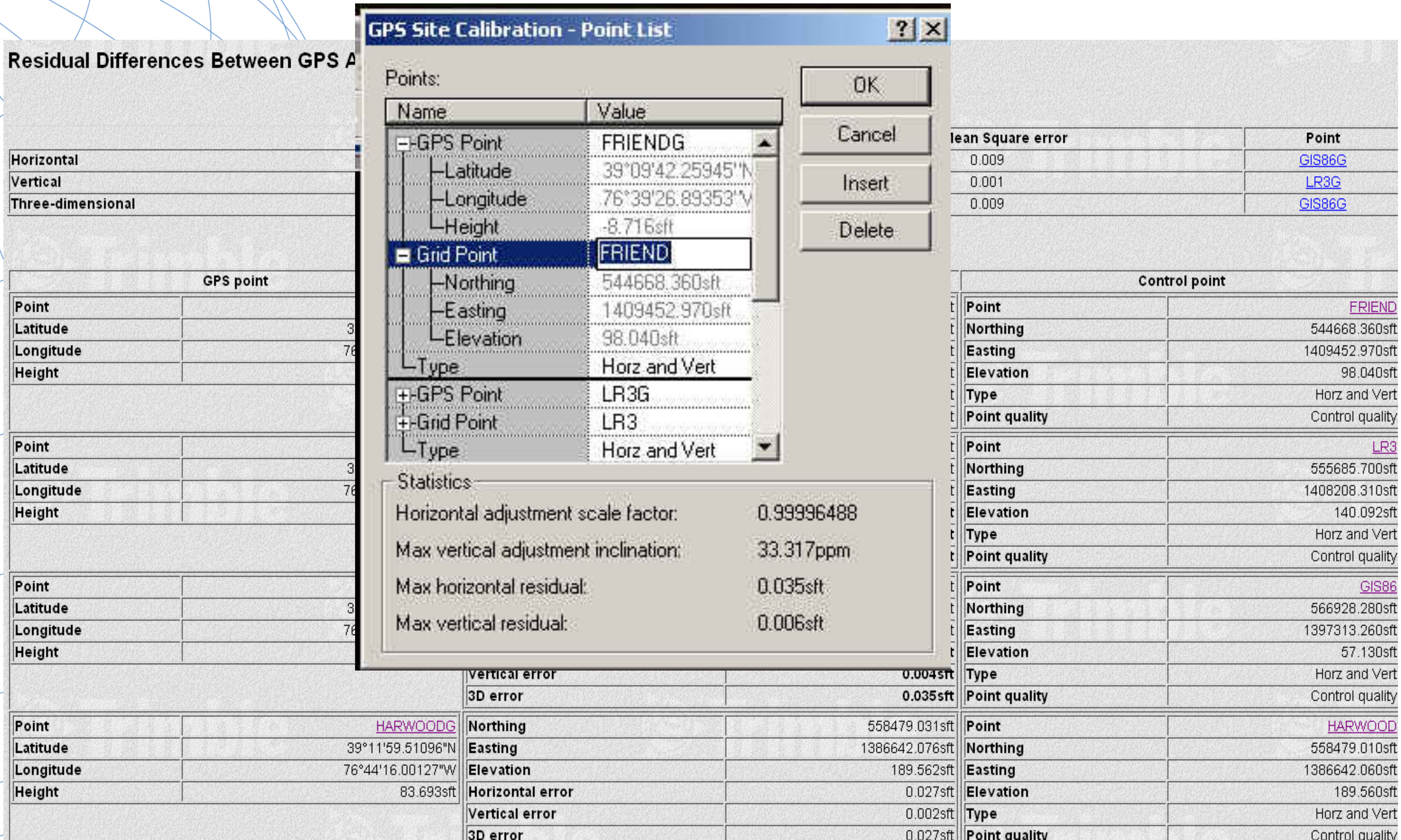
$$H_{88} = h_{83} - N_{09}$$

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 03
NAD 83 (CORS 96) USE GEOID 09
ITRF USE SCIENTIFIC GEOID (USGG)



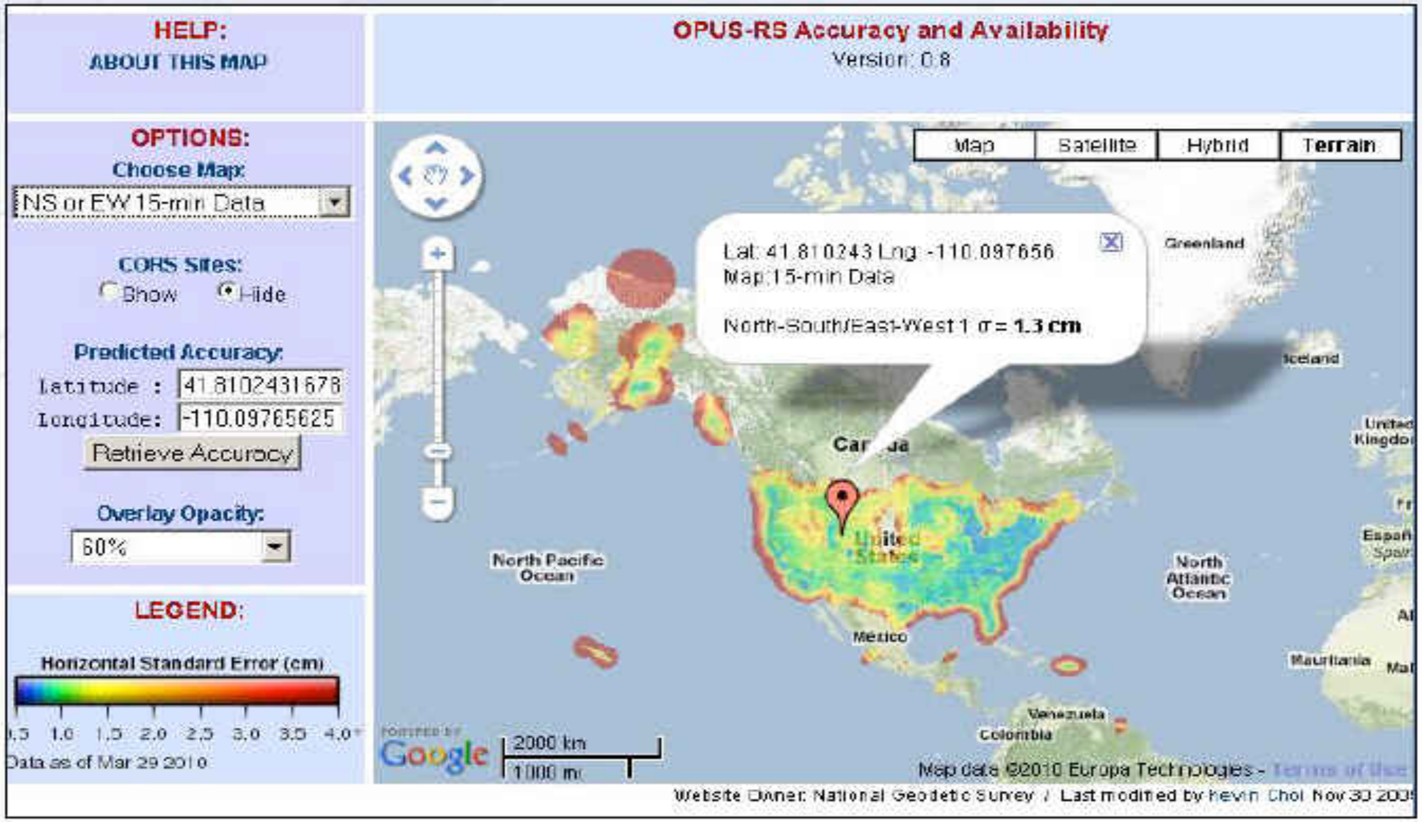
CALIBRATIONS/VERTICAL LOCALIZATIONS



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

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

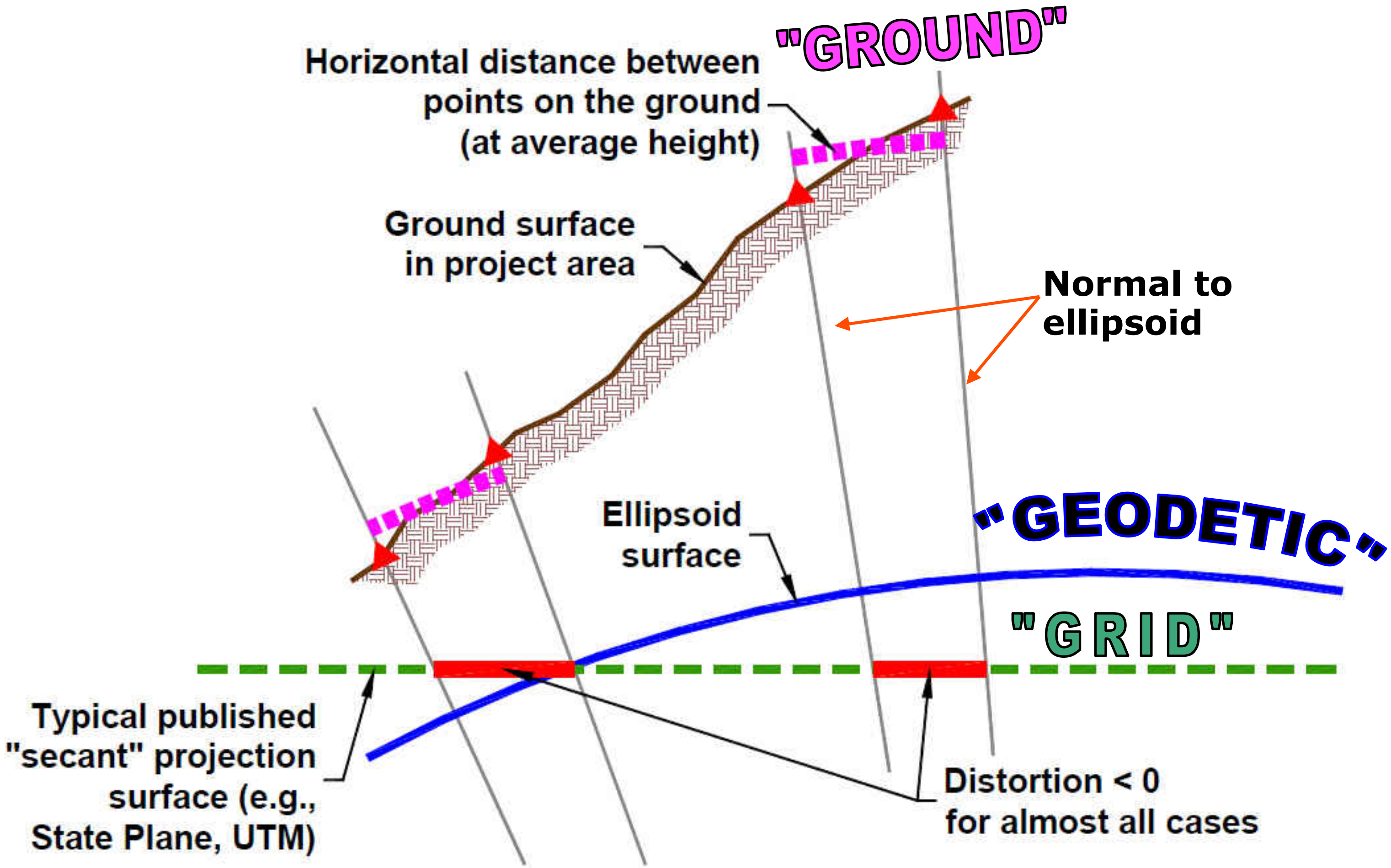
★ AUTONOMOUS LOCAL BASE STATION POSITION ARE OK IF CORRECT COORDINATES ARE INTRODUCED IN THE PROJECT FIRMWARE/SOFTWARE LATER

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.
- B REMEMBER GRID/GROUND

THREE SURFACES

Linear distortion due to ground height above ellipsoid

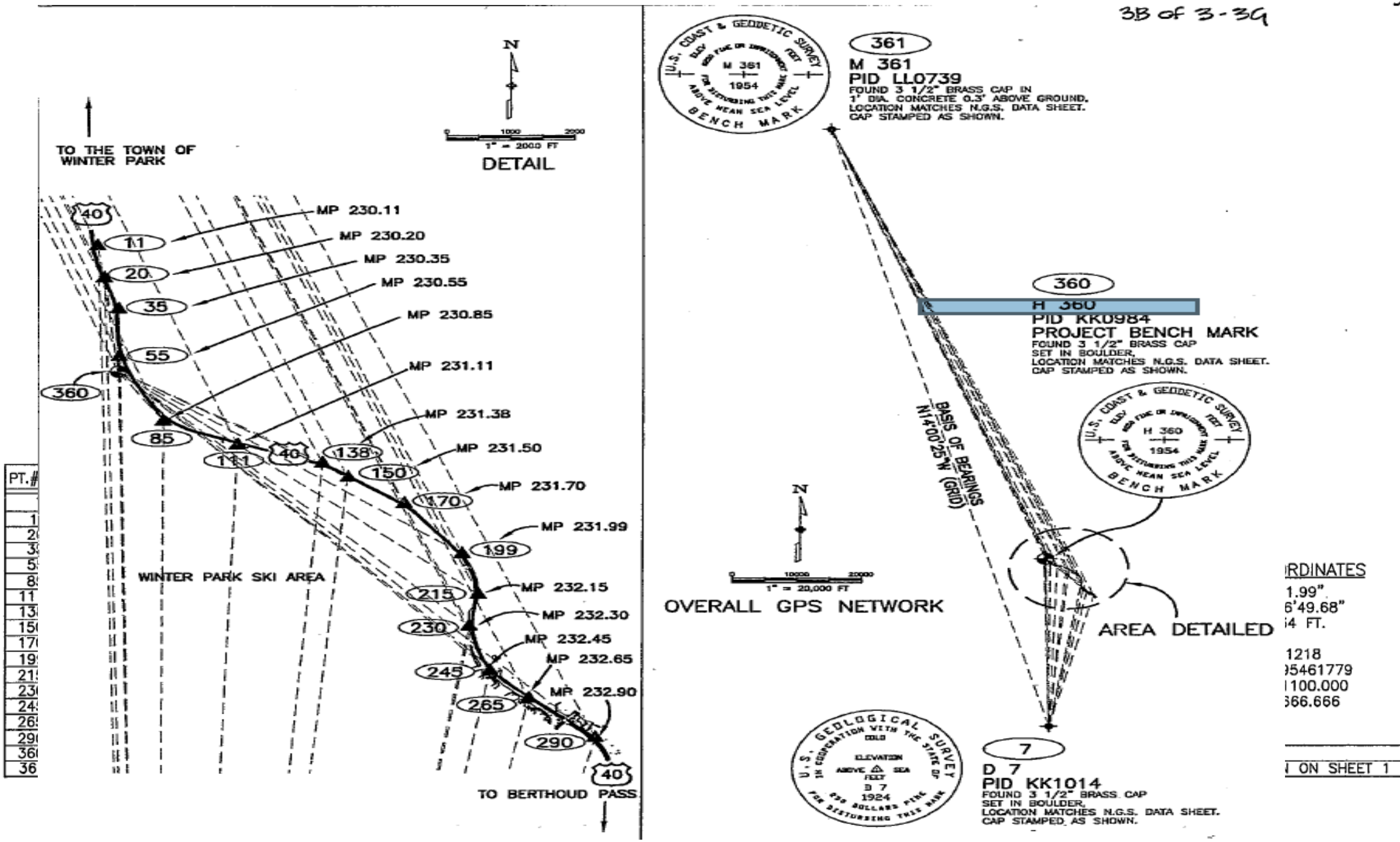


PROJECT SURFACE VS. GRID
IS YOUR DATA COLLECTOR CONFIGURED TO HANDLE THE TRANSFORMATION?

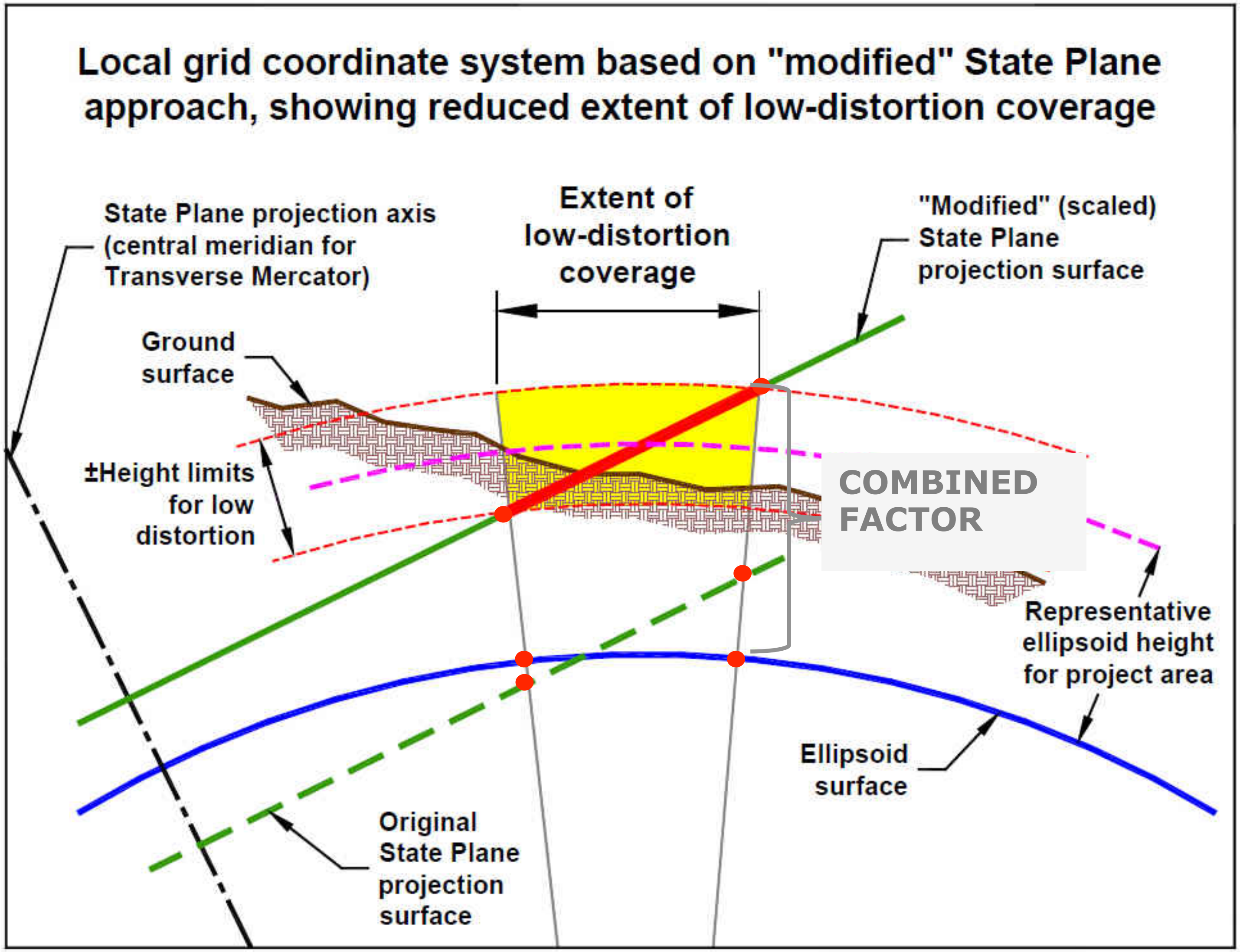
- FEATURES AND WORK ARE REFERENCED TO THE GROUND
- CONTROL MONUMENTATION IS USUALLY REFERENCE GRID
- THERE ARE DIFFERENT WAYS TO RESOLVE THIS:
  1. MODIFIED SPC
  2. LDP
  3. LOCALIZATION TO PASSIVE MONUMENTATION
  4. ASSUMED (TANGENT PLANE)

☞ A THOUGHT: RTN HAVE HOMOGENEOUS COORDINATES AND CAN ENCOMPASS LARGE REGIONS COMPOSSED OF MANY STATES. THERE ARE MANY LEGACY TRAVERSE CAMPAIGNS ACROSS PASSIVE MONUMENTATION USING DIFFERENT METHODOLOGY AND YIELDING DIFFERING ACCURACIES!

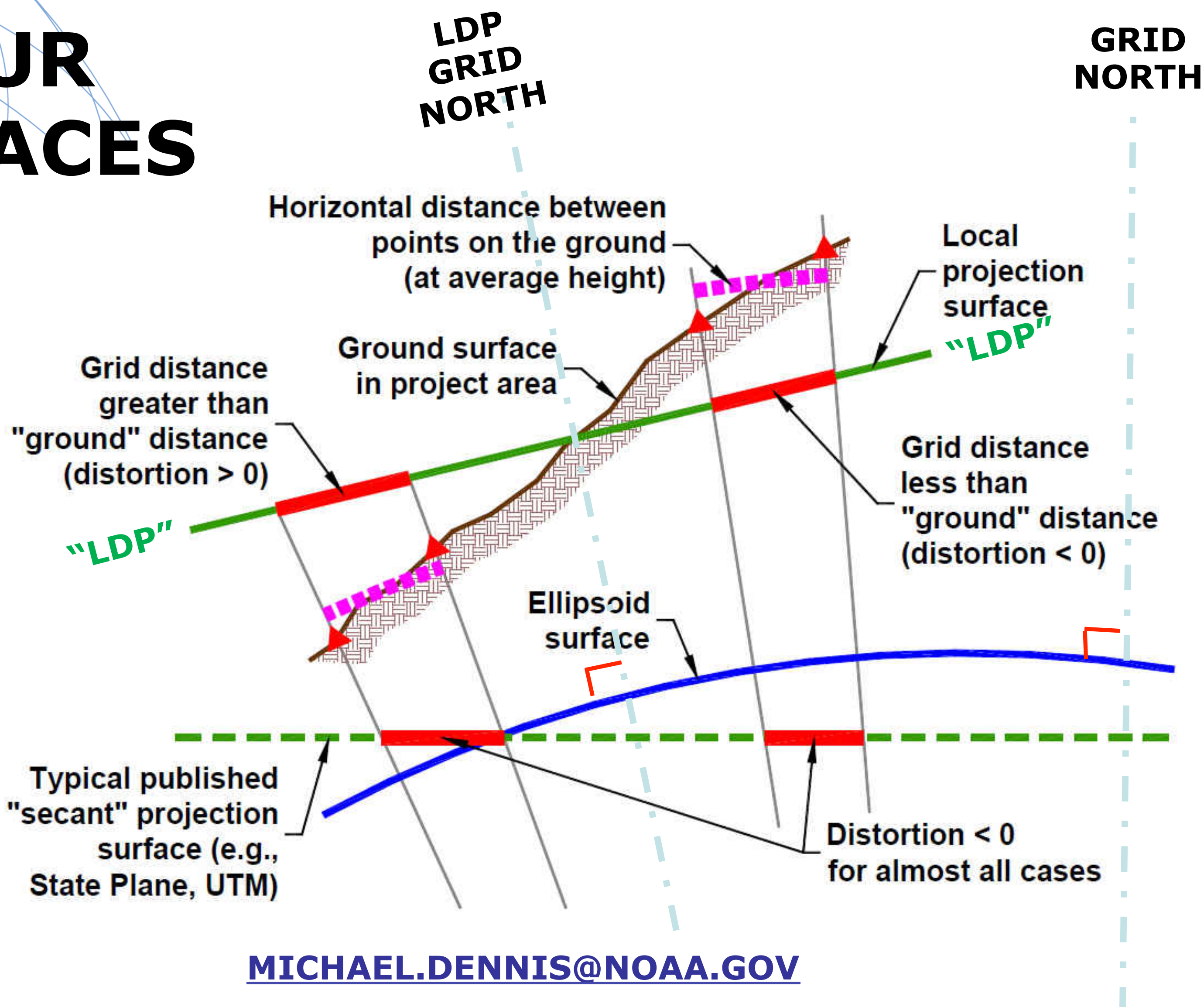
COLORADO DOT AND MODIFIED STATE PLANE



MODIFIED SPC- DOES NOT REDUCE CONVERGENCE ANGLE OR MINIMIZE DISTORTION



FOUR SURFACES



MICHAEL.DENNIS@NOAA.GOV

MESA COUNTY RTN & LOCAL COORDINATE ZONES

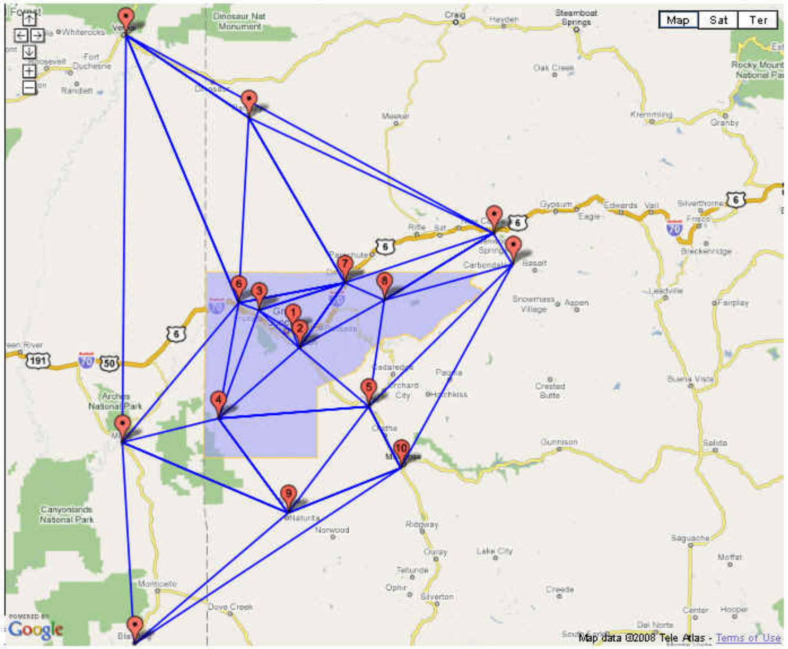
Mesa County Colorado

Survey CORS Base Station

Map of RTVRN (Real Time Virtual Reference Network)

RTVRN STATUS

Click on CORS Icon for detailed station information.



View Larger Map

Survey Information Management System (SIMS)

INTERACTIVE SIMS MAP | DOWNLOAD INFORMATIVE TEXT FILES | DOWNLOAD SHAPE (.shp) FILES

Vertical Datum Differences (NAVD29-88) | DOWNLOAD DATABASE (MS ACCESS) | DOWNLOAD TRIMBLE (TGO) FILES

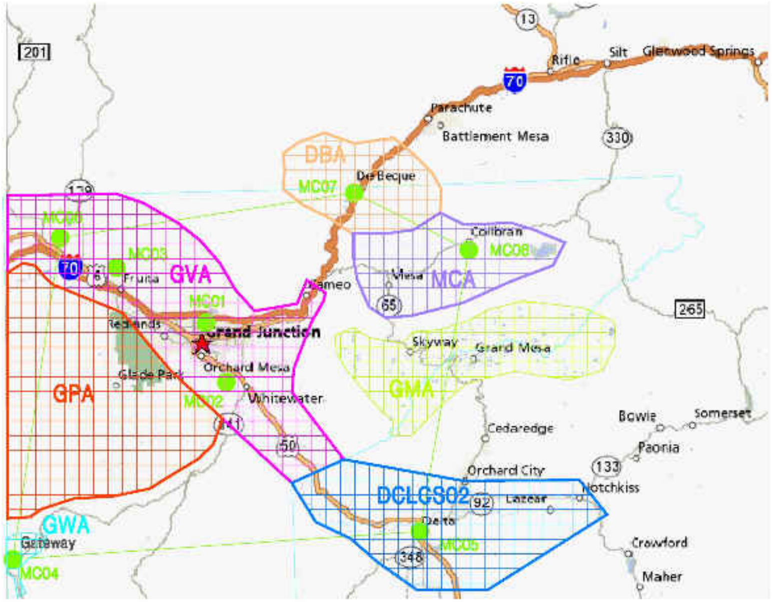
Mesa County Local Coordinate Systems | DOWNLOAD DRAWING FILES

Departments · Mesa County Home

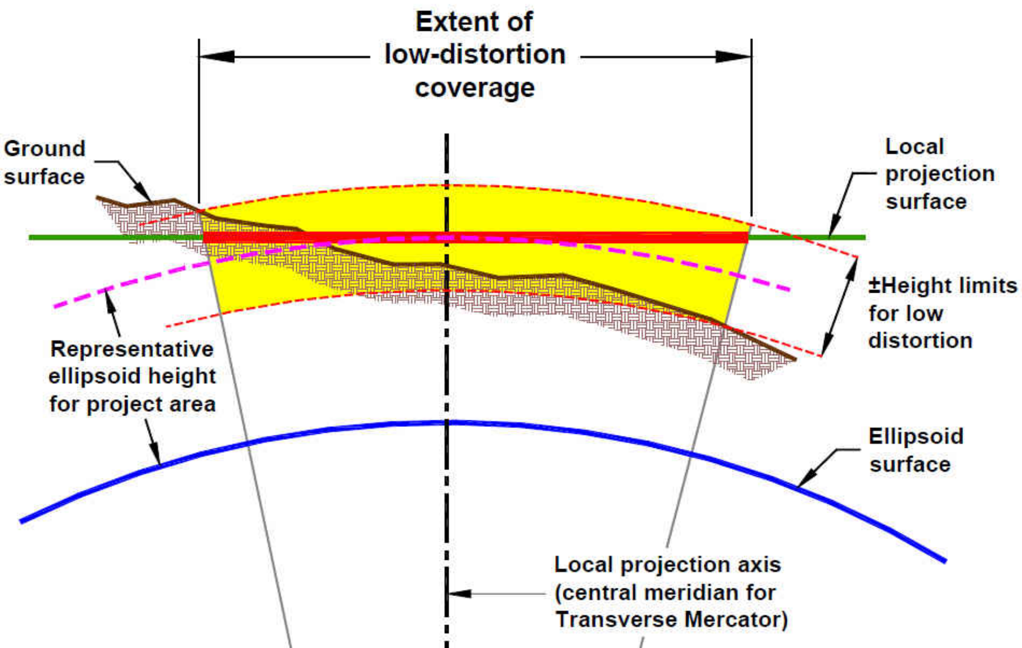
here to remove frame

GPS/SURVEY

Mesa County Local Coordinate Systems (MCLCS)



MESA COUNTY- LDP EXAMPLE



$$k_o = 1 + \frac{h_o}{R}$$

Mesa County Colorado

;PS Survey CORS Base Station

ınty Departments Mesa County Home

lick here to remove frame

GPS/SURVEY

GRAND VALLEY AREA

MCLCS ZONE "GVA"

TRANSVERSE MERCATOR PROJECTION

POINT OF ORIGIN (SN01)AND CENTRAL MERIDIAN:

LATITUDE: 39°06'22.72746N

LONGITUDE: 108°32'01.43552W

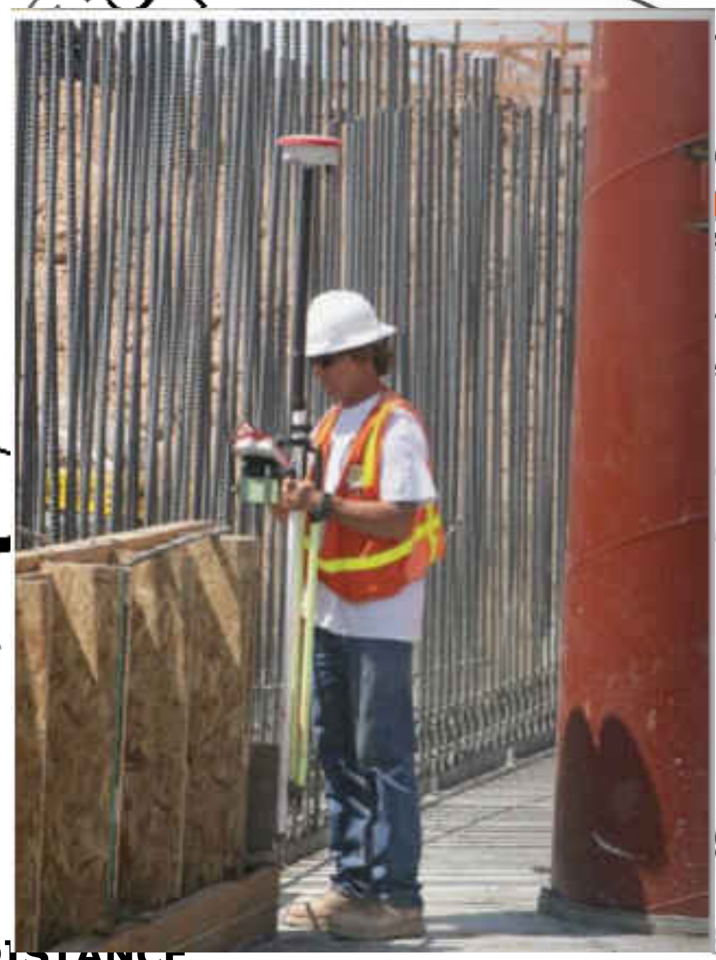
NORTHING: 50,000FT

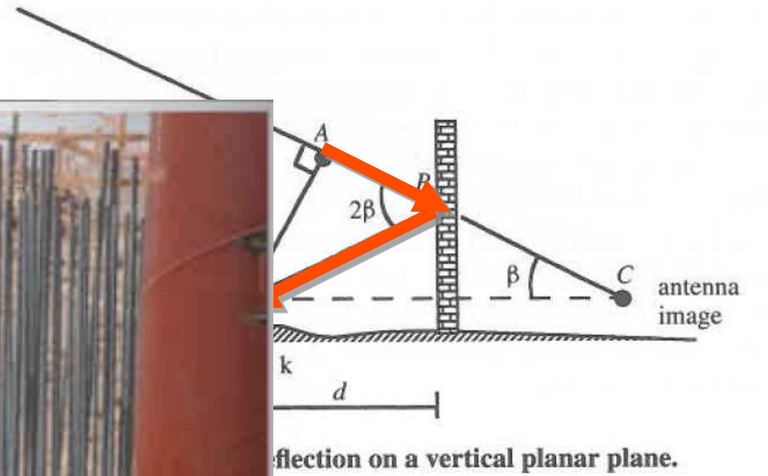
EASTING: 100,000FT

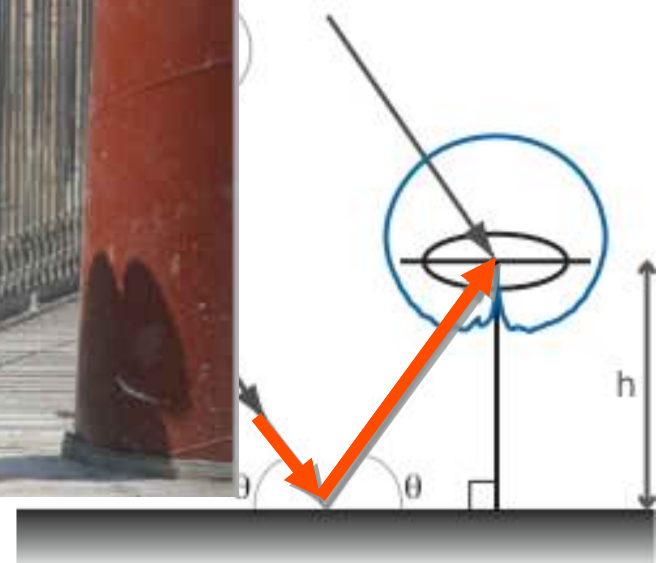
SCALE FACTOR: 1.000218181798

PROJECT/SCALE FACTOR HEIGHT: 4644FT(NAVD88)

MULTIPATH







= EXTRA DISTANCE

MULTIPATH = NOISE SPECULAR(DISCRETE) & DIFFUSE

INSIDE GNSS

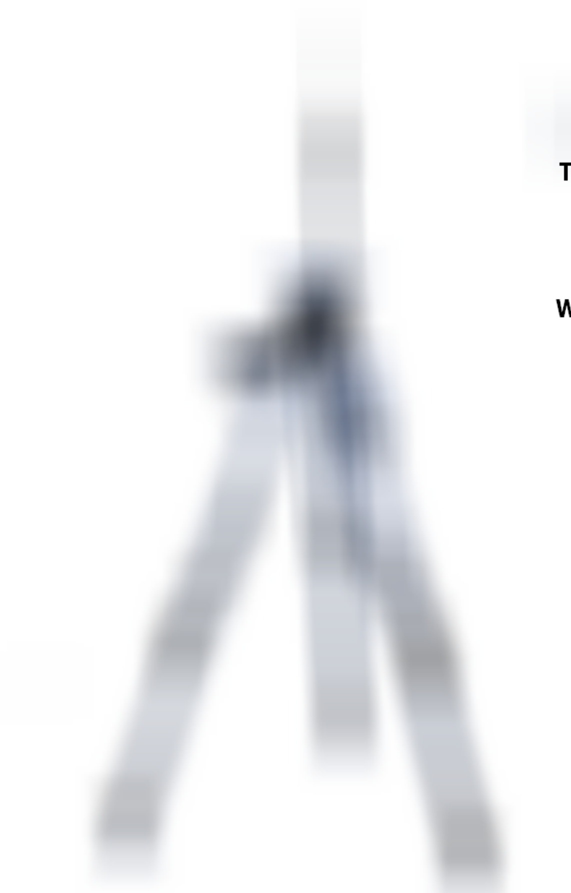
NOVEMBER-DECEMBER 2008

"MULTIATH-MITIGATION TECHNIQUES USING MAXIMUM-LIKELIHOOD PRINCIPLE"

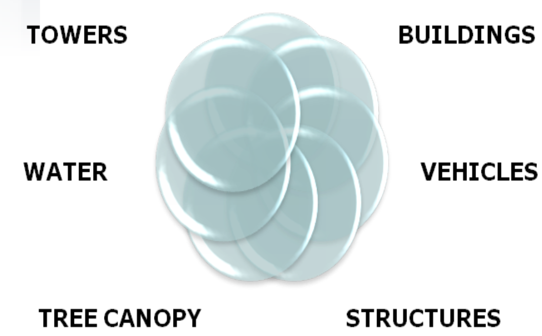
MOHAMED SAHMOUDI AND

RENE JR. LANDRY

WWW.INSIDEGNSS.COM



SOURCES:



NEWER GNSS GEAR & FIRMWARE IS BETTER!

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

CONFIDENCE

- B **CHECK** KNOWN BEFORE, DURING, AFTER SESSION. COMPARE POSITIONS WITH/ WITHOUT GLONASS.

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

ALSO-COMPARE GNSS POSITION TO GPS ONLY POSITION

(E.G., HIGH TENSION TOWER LINES)

Comparison of 30 Minute Solutions - Precise Orbit; Hopfield (0); IONOFREE

(30 Minute solutions computed on the hour and the half hour)

MOLA to RV22 10.8 Km

THE IMPORTANCE OF REDUNDANCY

Day 264	dh (m)	Hours Diff.	Day 265	dh (m)	Day 264 minus Day 265 (cm)	* diff >2 cm	Mean dh (m)	Mean dh minus "Truth" (cm)	* diff >2 cm
14:00-14:30	-10.281	27hrs	17:00-17:30	-10.279	-0.2		-10.280	-0.5	
14:30-15:00	-10.278	27hrs	17:30-18:00	-10.270	-0.8		-10.274	0.2	
15:00-15:30	-10.281	27hrs	18:00-18:30	-10.278	-0.3		-10.280	-0.4	
15:30-16:00	-10.291	27hrs	18:30-19:00	-10.274	-1.7		-10.283	-0.7	
16:00-16:30	-10.274	27hrs	19:00-19:30	-10.274	0.0		-10.274	0.2	
16:30-17:00	-10.287	27hrs	19:30-20:00	-10.276	-1.1		-10.282	-0.6	
17:00-17:30	-10.279	27hrs	20:00-20:30	-10.261	-1.8		-10.270	0.6	
17:30-18:00	-10.270	27hrs	20:30-21:00	-10.251	-1.9		-10.261	1.5	
18:00-18:30	-10.277	21hrs	15:00-15:30	-10.270	-0.7		-10.274	0.2	
18:30-19:00	-10.271	21hrs	15:30-16:00	-10.276	0.5		-10.274	0.2	
19:00-19:30	-10.277	21hrs	16:00-16:30	-10.278	0.1		-10.278	-0.2	
19:30-20:00	-10.271	21hrs	16:30-17:00	-10.286	1.5		-10.279	-0.3	
20:00-20:30	-10.259	18hrs	14:00-14:30	-10.278	1.9		-10.269	0.7	
20:30-21:00	-10.254	18hrs	14:30-15:00	-10.295	4.1	*	-10.275	0.1	
							"Truth"		
14:00-21:00	-10.275		14:00-21:00	-10.276	0.1		-10.276		

Two Days/Same Time

-10.254
-10.251 > -10.253

Difference = 0.3 cm

"Truth" = -10.276

Difference = 2.3 cm

Two Days/ Different Times

-10.254
-10.295 > -10.275

Difference = 4.1 cm

"Truth" = -10.276

Difference = 0.1 cm

RT SINGLE BASE GUIDELINES- 95% CONFIDENCE

ACCURACY CLASS SUMMARY TABLE

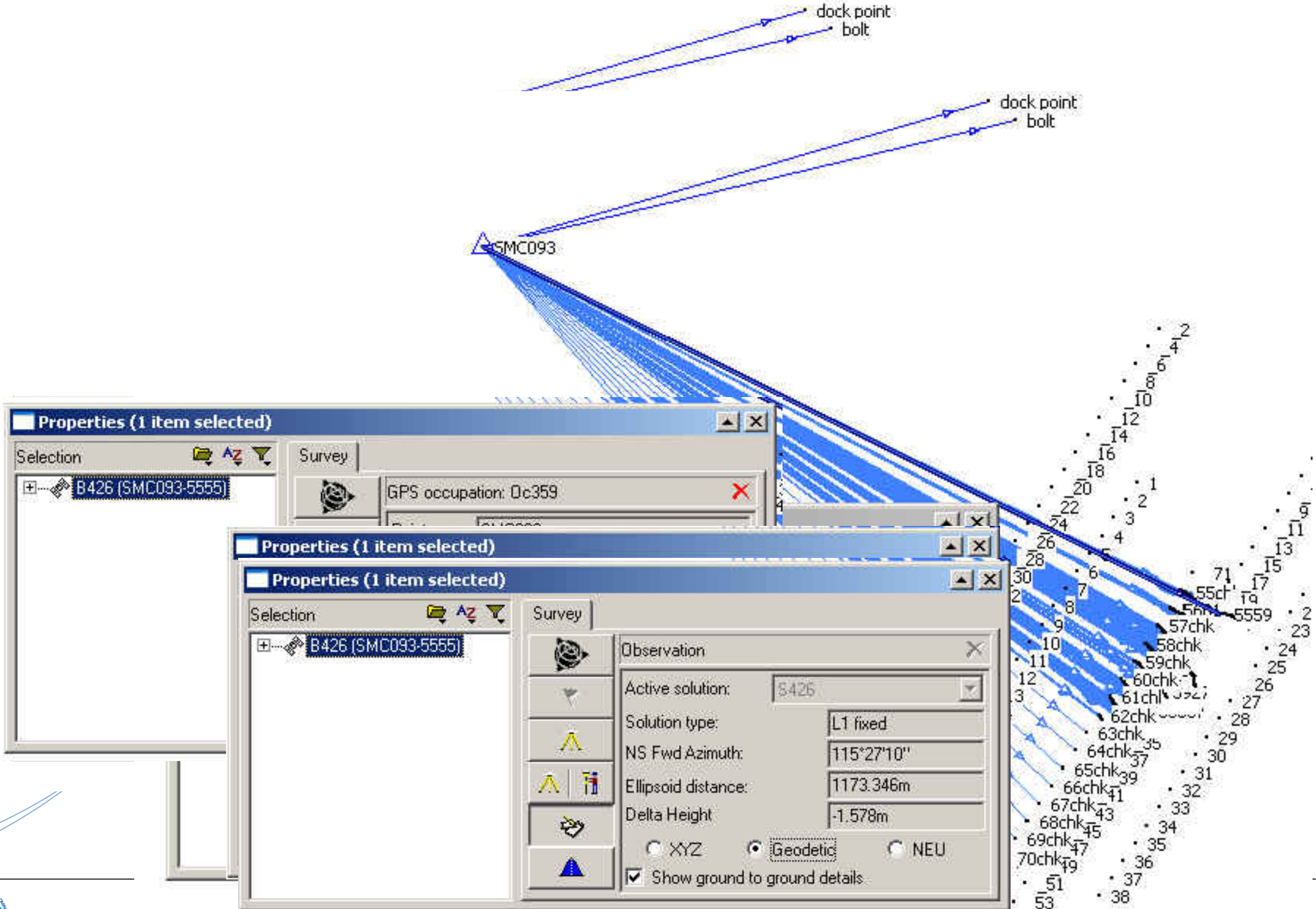
	CLASS RT1	CLASS RT2	CLASS RT3	CLASS RT4
ACCURACY (TO BASE)	0.015 HORIZONTAL., 0.025 VERTICAL	0.025 HORIZONTAL., 0.04 VERTICAL	0.05 HORIZONTAL., 0.06 VERTICAL	0.15 HORIZONTAL., 0.25 VERTICAL
REDUNDANCY	≥ 2 LOCATIONS, 4-HOUR DIFFERENTIAL	≥ 2 LOCATIONS, 4-HOUR DIFFERENTIAL	NONE	NONE
BASE STATIONS	≥ 2 , 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 PHOTOPOINTS UTILITY STAKE OUT	TOPOGRAPHY CROSS SECTIONS AGRICULTURE ROAD GRADING SITE GRADING	SITE GRADING WETLANDS GIS POPULATION MAPPING ENVIRONMENTAL

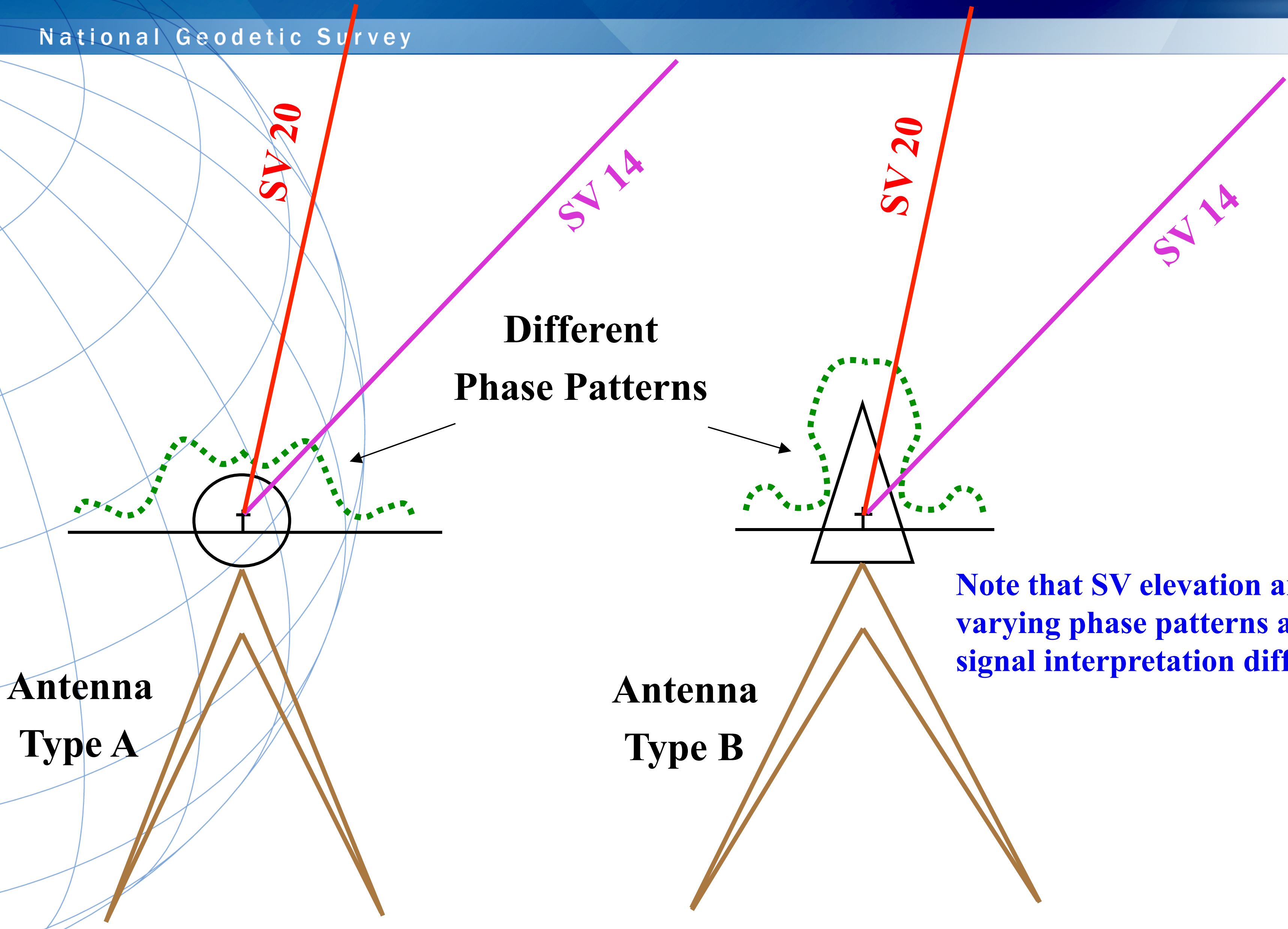
CHAPTER V. PAGE 48- FIELD PROCEDURES

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





Note that SV elevation and varying phase patterns affect signal interpretation differently

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)

QUICK FIELD SUMMARY:

- Set the base at a wide open site
- Set rover elevation mask between 12° & 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

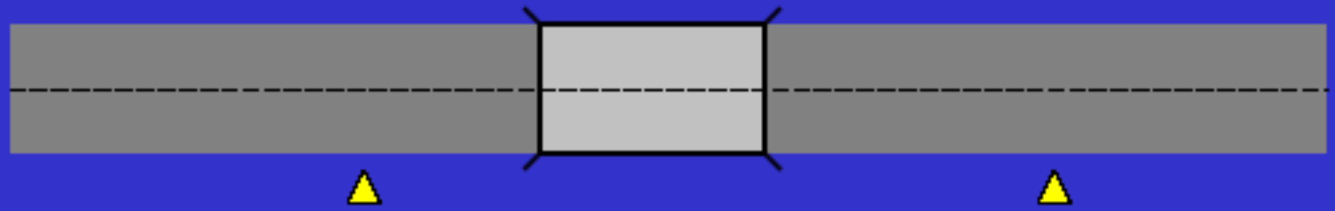
KNOW YOUR METADATA

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

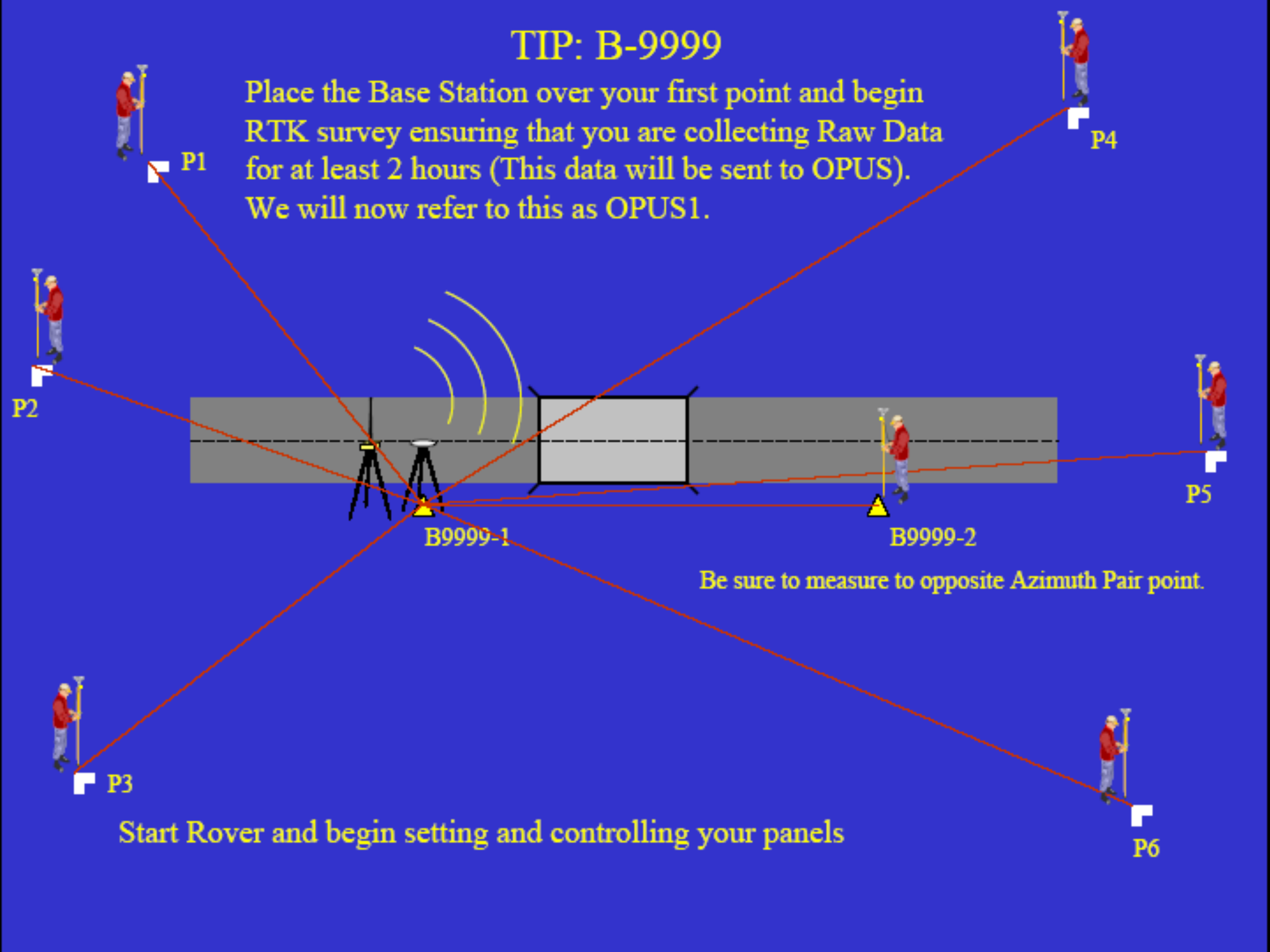
↓

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

USING OPUS-S OR OPUS –RS WITH REAL TIME POSITIONING FOR SMALL PROJECTS- NO RTN COMMUNICATION

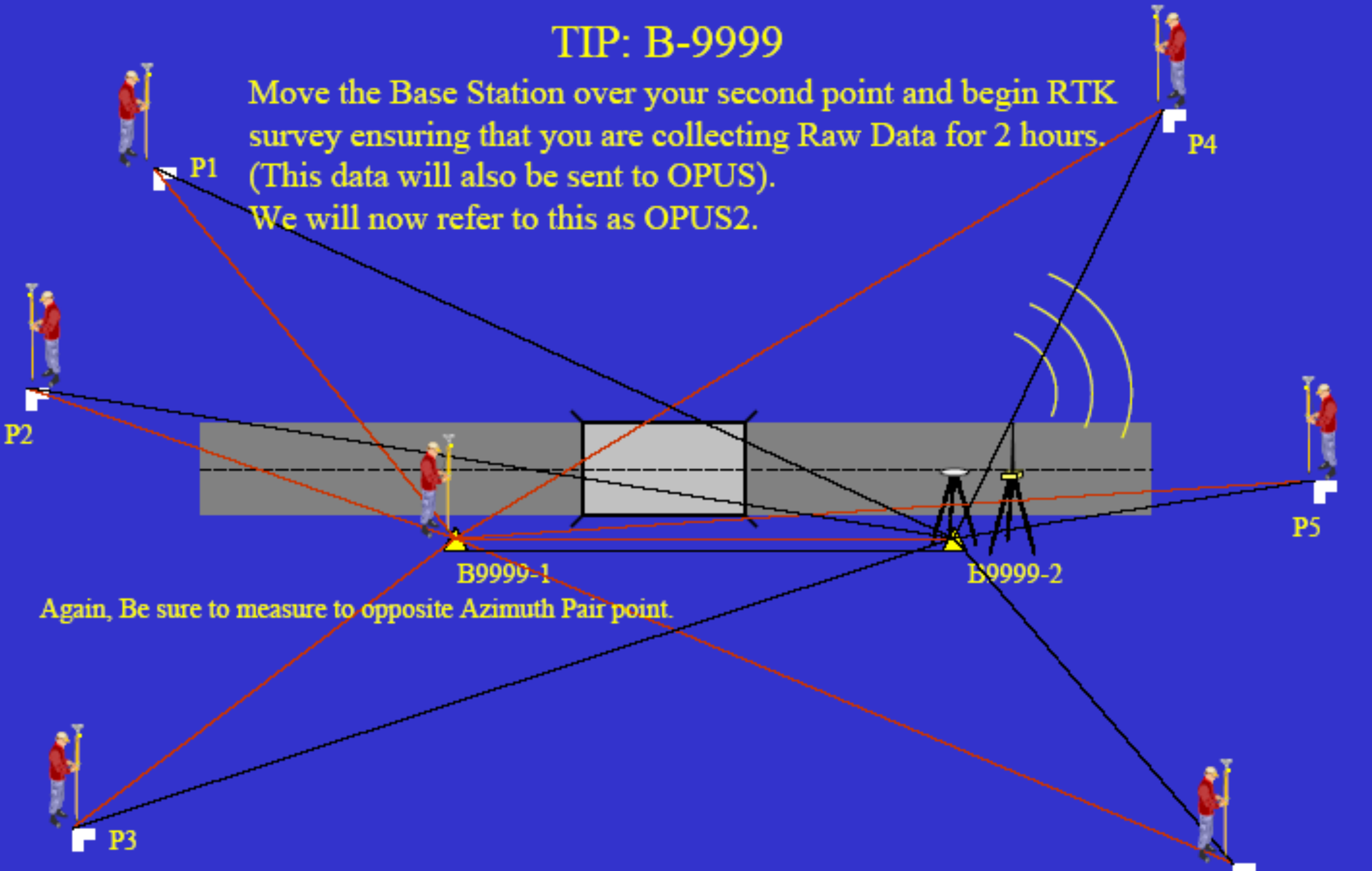


On a typical Bridge job we set an azimuth pair and have approximately 6-7 panels to control. Following is an example of how we can effectively control this site with 2 receivers.


TIP: B-9999
Place the Base Station over your first point and begin RTK survey ensuring that you are collecting Raw Data for at least 2 hours (This data will be sent to OPUS).
We will now refer to this as OPUS1.
P1
P2
P3
P4
P5
P6
B9999-1
B9999-2
Be sure to measure to opposite Azimuth Pair point.
Start Rover and begin setting and controlling your panels

TIP: B-9999

Move the Base Station over your second point and begin RTK survey ensuring that you are collecting Raw Data for 2 hours. (This data will also be sent to OPUS). We will now refer to this as OPUS2.



Start Rover and begin controlling your panels from the second location. If you use one controller and name the points the same the controller will provide comparisons in the field.

THE QUICK SUMMARY BOILED DOWN: FOUR CARDINAL RULES FOR RT POSITIONING

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

≥200 RTN WORLDWIDE
≥107 RTN IN THE USA
≥35 DOT WITH STATEWIDE NETWORKS OPERATING OR PLANNED