VRS – IMPROVING SINGLE BASE GPS ACCURACY

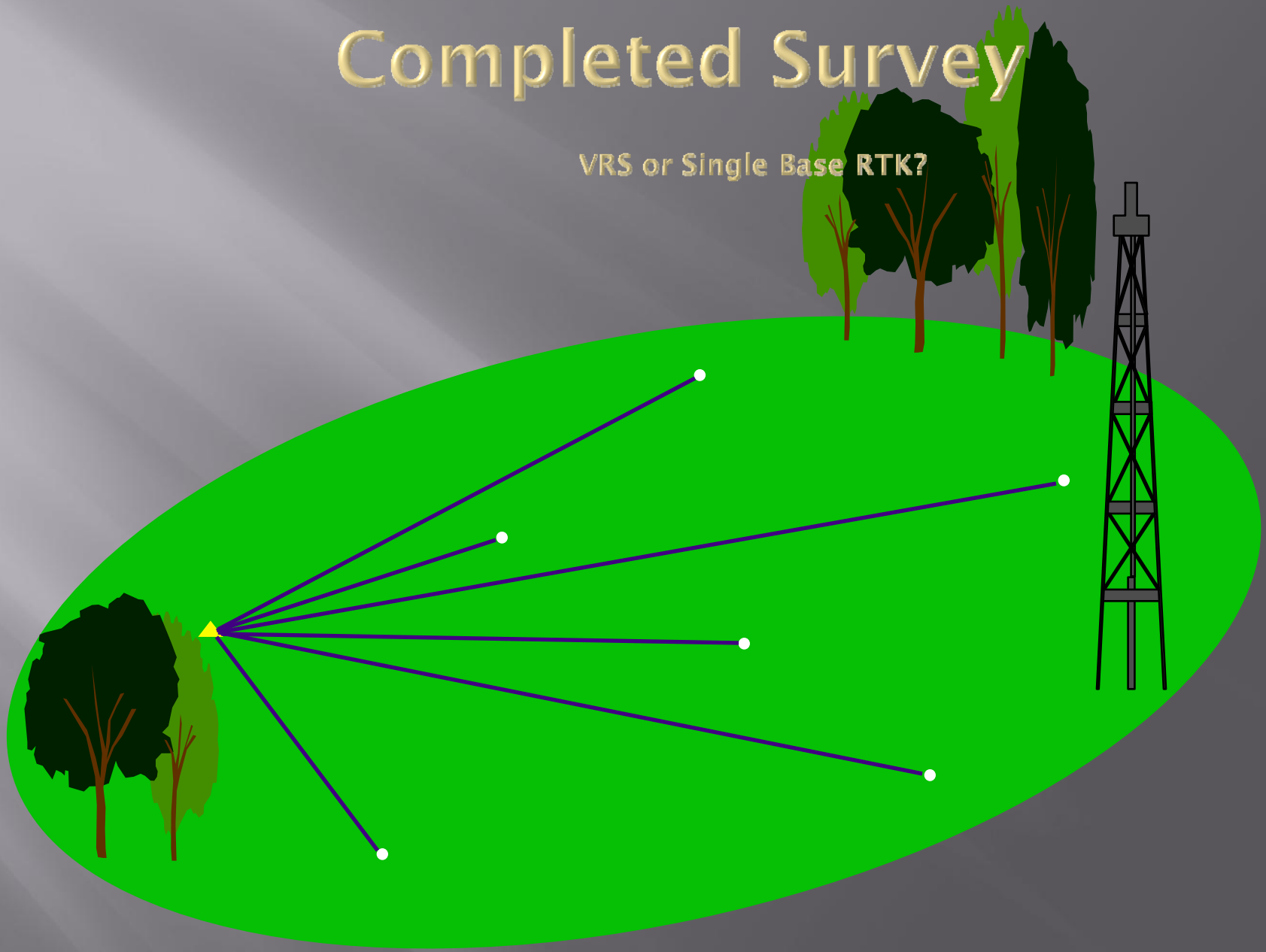
David Janssens, P.L.S.
Winnipeg, Manitoba

What we are going to Cover

- What is Single Base RTK – why use it?
- Accuracies with GPS (single base vs. VRS)
- What is VRS – Is it Better?
- Ionosphere - Why is it important?
- How does a VRS work?
  - Advantages
  - Dis-Advantages
  - Security
  - Comparison

Completed Survey

VRS or Single Base RTK?



Sigma Values

- Precision = repeatability of measurement
- 1 sigma = Precision of instrument at 68% confidence or 68 out of 100 measurements are within the specified tolerance
- 2 sigma = Precision of instrument at 95% confidence or 95 out of 100 measurements are within the specified tolerance
- 3 sigma = Precision of instrument at 99% confidence or 99 out of 100 measurements are within the specified tolerance

Accuracy Comparison

Single Base Station (2 sigma or 95% confidence level)

Horizontal: 1cm ± 1ppm

Vertical: 2cm ± 1ppm

1ppm equals 1cm every 10km away from the base station - Horizontal.

1ppm equals 1cm every 10km away from the base station - Vertical.

VRS (2 sigma or 95% confidence level)

Horizontal: 1cm ± 0.1ppm

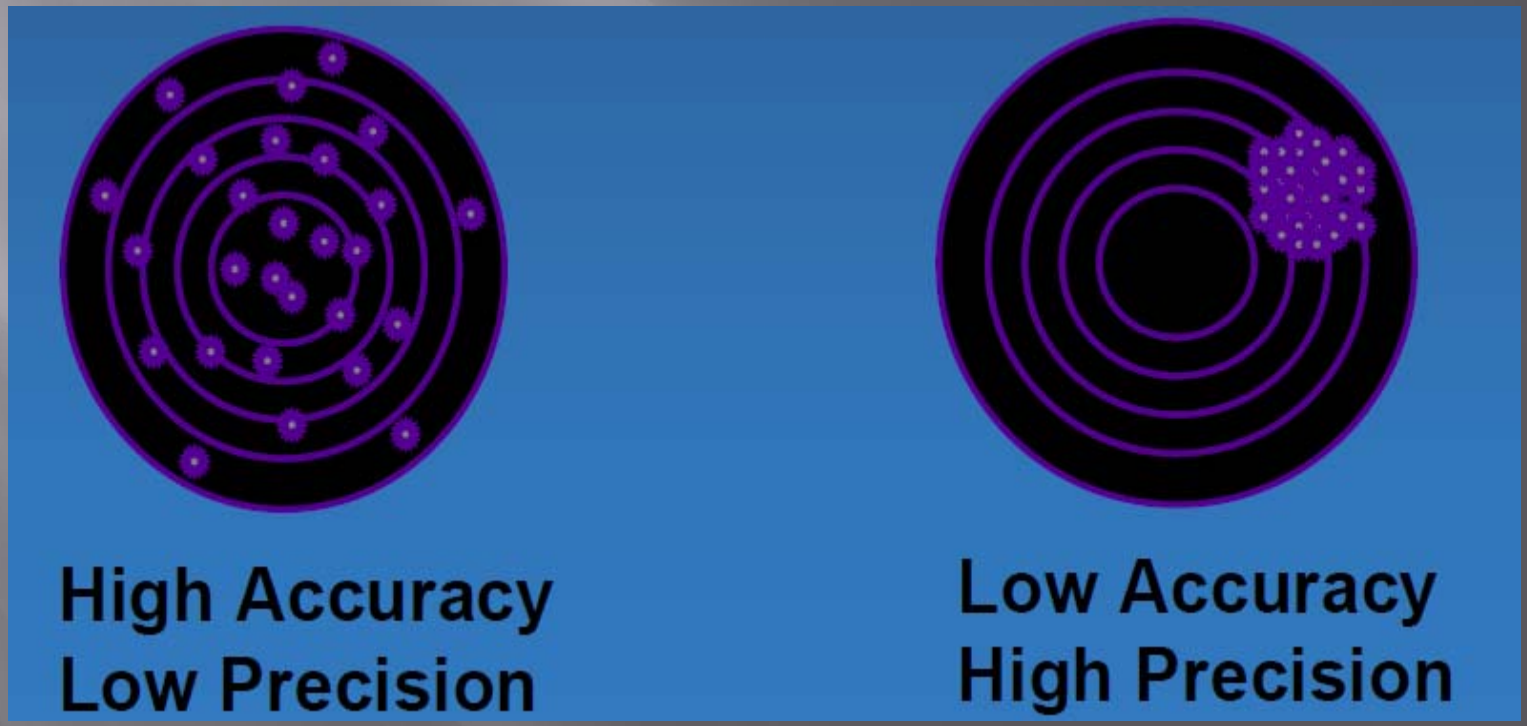
Vertical: 2cm ± 0.1ppm

0.1ppm equals 1mm every 10km away from the base station within VRS- Horizontal.

0.1ppm equals 1mm every 10km away from the base station within VRS - Vertical.

Accuracy/Precision

- Remember that GPS is highly precise, but accuracy comes from the quality of your surveyed reference station (RMS).



SINGLE BASE STATIONS

What is Single Base Station RTK

- One baseline from Base station to surveyor
- PPMs increase with distance
  - 1ppm error per kilometer away from the base station (1mm every kilometer).
- Typically uses a UHF radio band frequency (430 -470 MHz)
- No monthly costs for data transmission
- Easily moved

Advantages

- Great for small surveying applications
- One time cost for base
- Radio works anywhere

Dis-Advantages

- No redundancy

- Does not model the atmospheric conditions
- No ability to check system for errors
- Limit range of single station with radio
- Errors grow with baseline length (ppm)
- Reliability and performance decrease with distance to the next reference station.
- Base safety
- Are the single reference stations tied to each other.

VRS

VRS – Virtual Reference Station

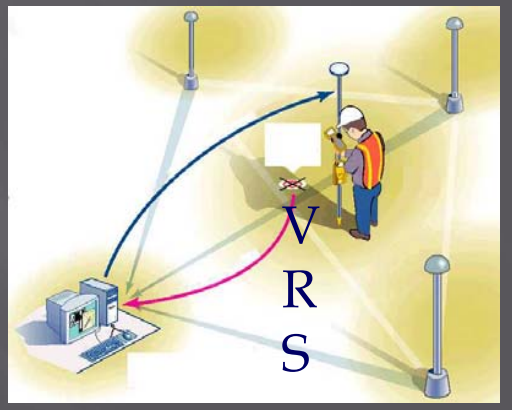
What is it?

- Series of GPS base stations that continuously collect information from each GPS receiver in the network, modeling the atmospheric corrections which minimizes the ionospheric effects.

- Creates a virtual reference station close to the user, thus eliminating ppm error sources.

- Applying them at the rover so that centimetre accuracy is maintained anywhere in the VRS network.

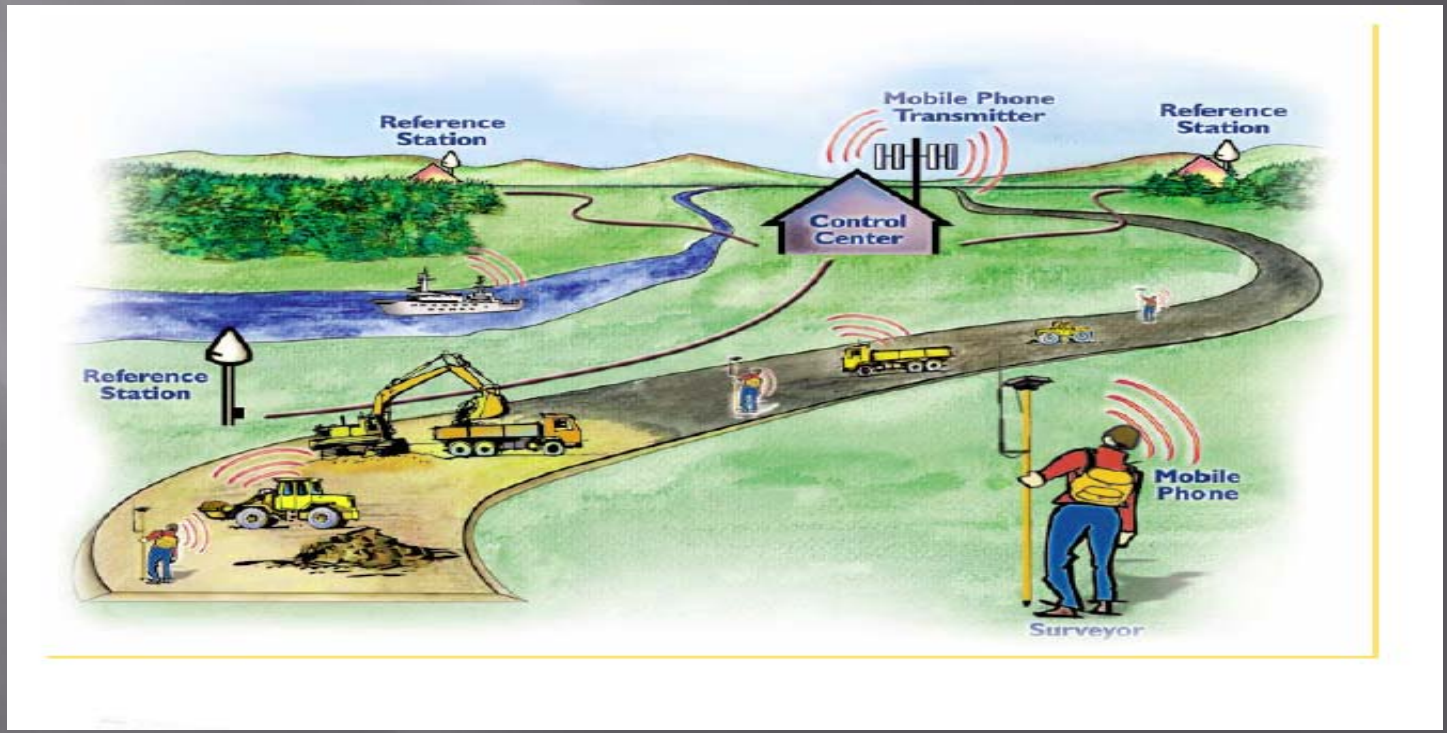
- Covers a large area with a minimum number of base stations.



  - Base stations typically 50 - 70km apart.
  - VRS - 70 km square needs 4 base stations.
  - Single base – 70 km square needs at least 8 base stations plus multiple repeaters.

Cont'd

- Redundancy and error checking.
- Developed and used for:
  - Survey/engineering applications
  - *1cm horizontal, 2cm vertical accuracy anywhere in the network.*



Why do you need Networked GPS?

- Consistency of data using a common coordinate system
- Bi-directional data streams
- Data storage
- Common configuration of all reference stations in a network (i.e. elevation masks, data storage, sv tracking)
- Modelling of error sources
  - Quality control
  - Reporting
  - Alarm generation
  - Web Services

Base Station Installation

- Clear Sky view
  - 100 meters unobstructed view to the horizon 360 degrees
- No nearby signal reflectors
  - 0.5 metres above horizontal surfaces
- No nearby signal transmitters
  - 300 metres away from a transmission source
- Stability
  - Thermal expansion
  - Wind loading
  - Soil expansion/contraction
- Conditions must not change with time!

Base Stations Photos

Base Stations Photos

Why level and orient adaptor

- Antenna ARP will maintain same 3D position if antenna is replaced.

Reference Station Components

- Electronic Component
  - GPS receiver
  - Network Router
- Uninterruptible Power Supply UPS
- Electrical Surge Protection
- Equipment Location
  - Enclosure
- Internet Box
- GPS Antenna Component
  - GPS Antenna
  - Location
  - Mounting
- GPS Antenna Cable Component
  - Routing
  - Lightning protection
  - Grounding

Provincial Control Integration

- Not a trivial task to meet Provincial Standards.
- Static observation to control monument typically using CSRS NAD 83.
- Correct Epoch
- Minimum observation periods of 24hrs x 2 sessions per control tie.
- Additional Independent Validation Survey.
- Specific Processing and Adjustment procedures
- Licensed Land Surveyor independently checks the coordinates of each base station – certifies the system.
- Allows the user to tie directly to provincial control, so that GIS or aerial photography can be imported for use.

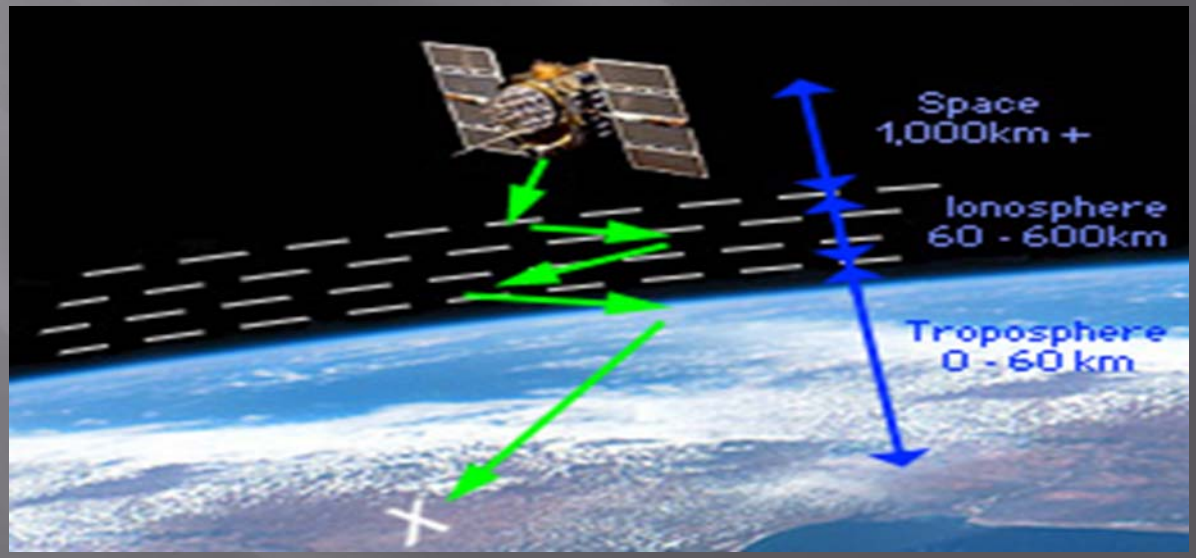
IONOSPHERE AND TROPOSPHERE

Tropospheric Model

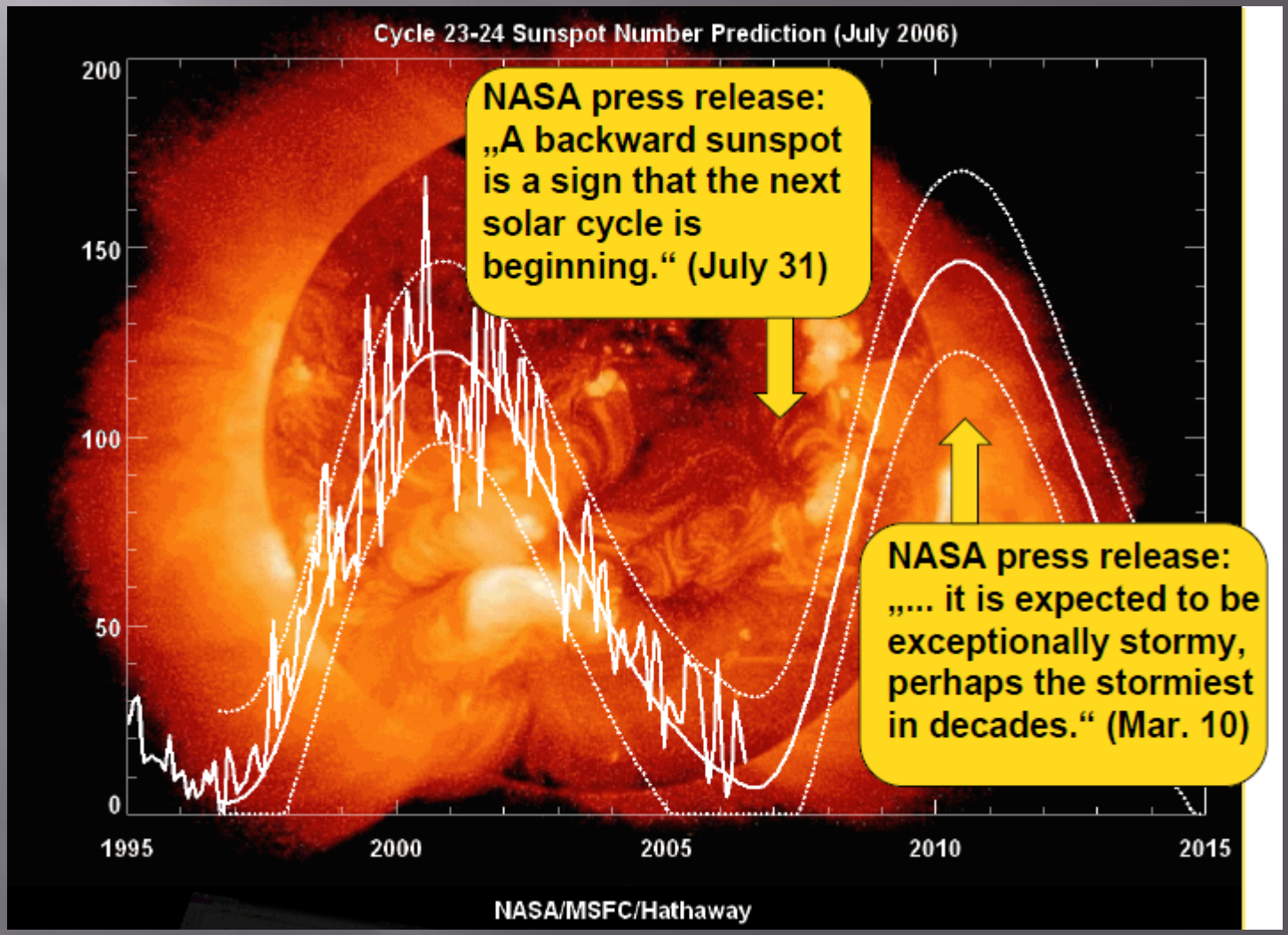
- Troposphere is part of the atmosphere
- Model is needed to determine the influence on signal propagation time
- Model is calculated based on the signals used within the software
- Model is continuously updated

Impact of the Ionosphere

- Ionosphere is influenced by solar storms
- Ionosphere causes a modification of the propagation time of the signal between satellite and earth
- Model within software to calculate the influence of ionized particles
- Results in improved performance = VRS

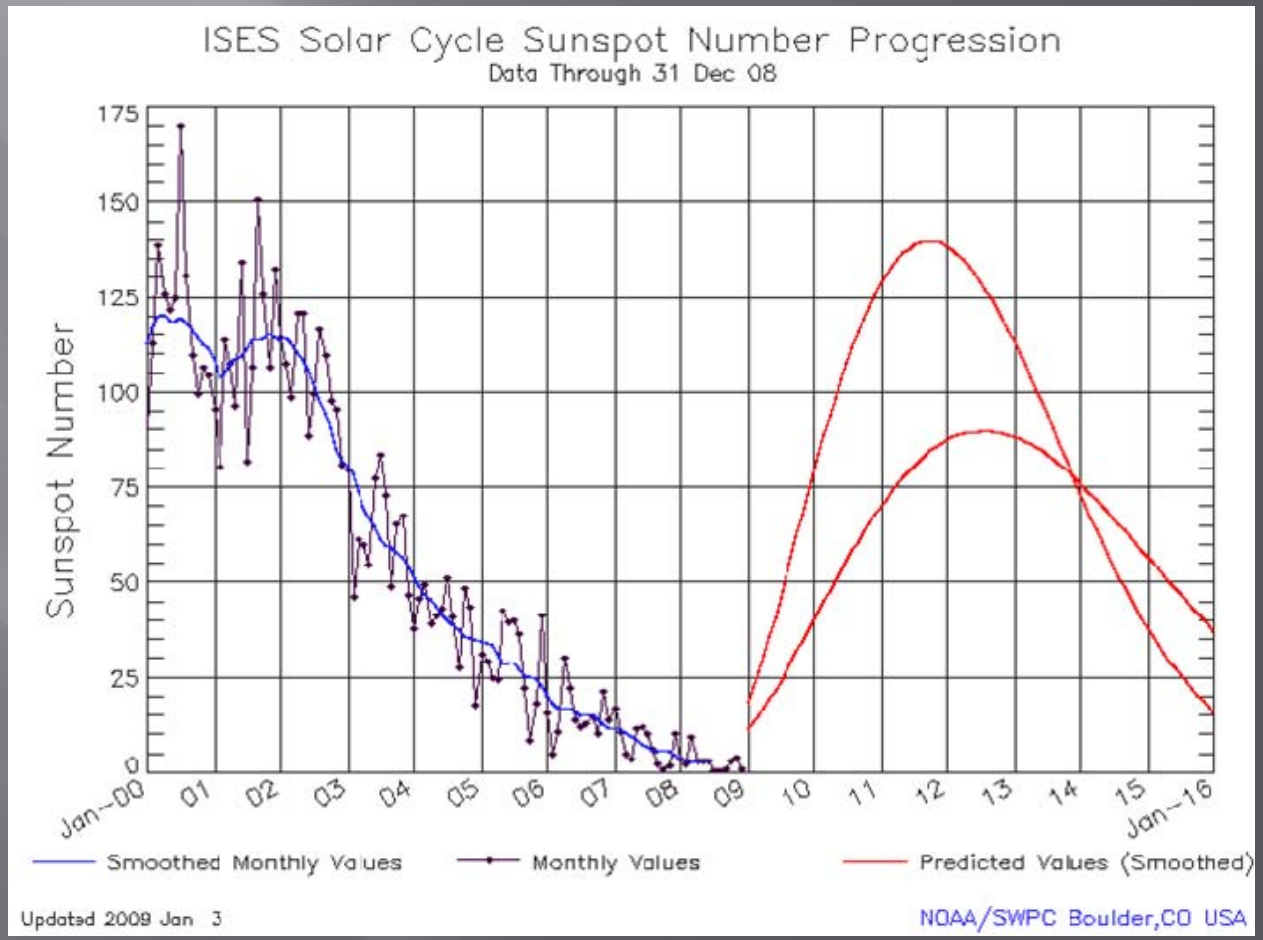


Ionosphere from 1996 to Present



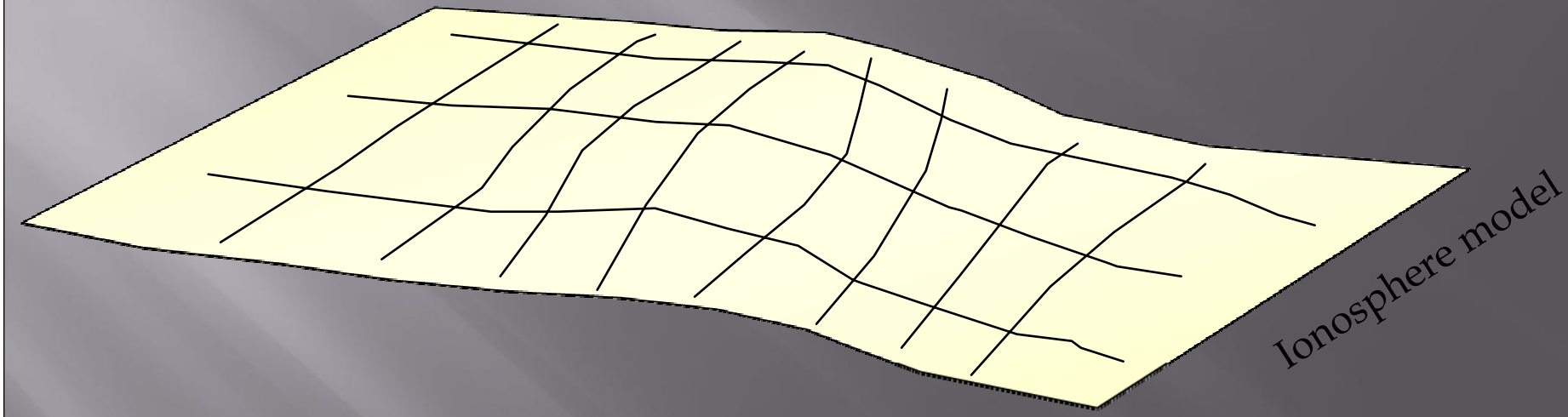
Ionospheric Simulation

- http://www.windows2universe.org/spaceweather/sun_earth9.html



Ionospheric model example

Interpolates the ionospheric effect from the closest 6 base stations



Total Electron Count – TEC

- Total electron count (TEC) is a measure used to characterize the conductivity of the ionosphere, which consists of ionized layers of the upper atmosphere.
- Free electrons in the ionosphere affect the transmission of radio waves by absorbing and reflecting, which slows the propagation of radio signals through the ionosphere.
- Estimates of the TEC can be used to correct for transmission delays in GPS signals, which can be incorporated in GPS receivers for more accurate location estimates.

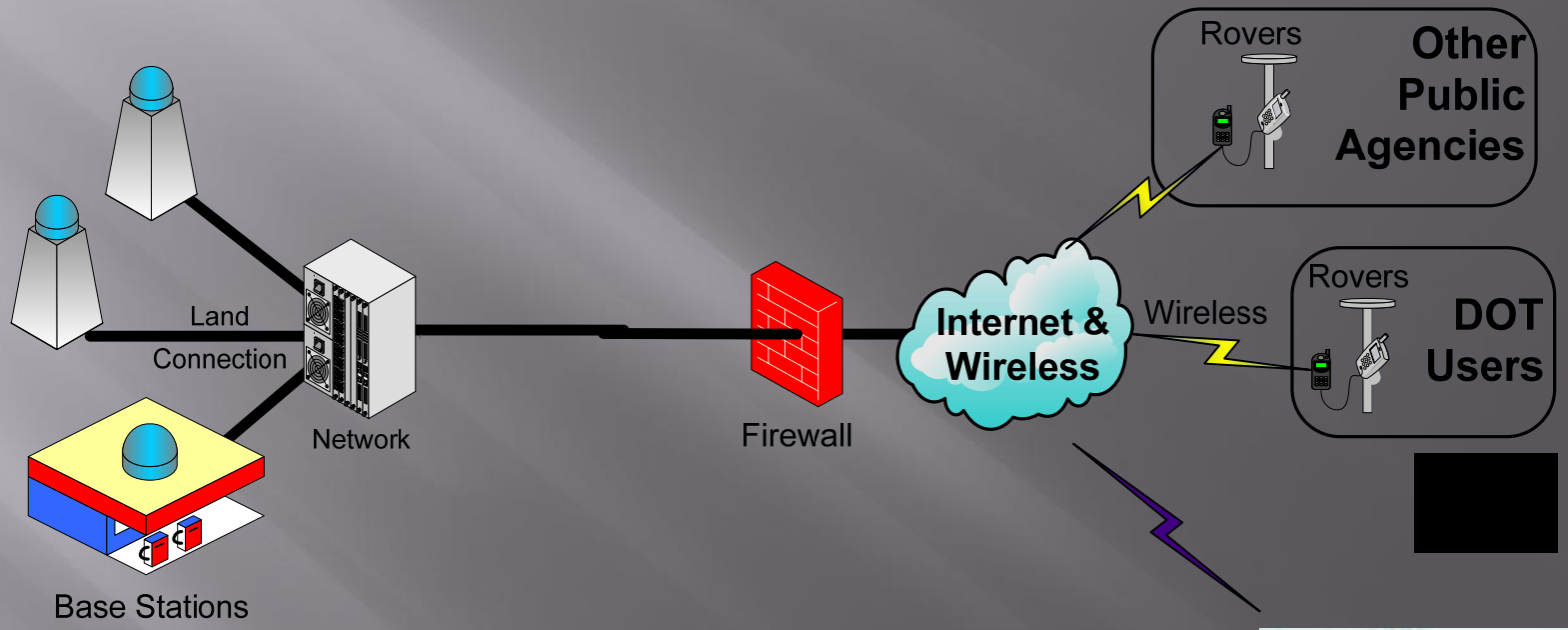
Ionospheric Storms

- Solar Flares and coronal mass ejections.
- Generate large disturbances in ionospheric density distribution, which affects the TEC.
- VRS software allows the prediction of the effect of ionospheric activity.
- Uses the 6 closest base stations to interpolate the ionospheric effect on the users location.

- Go to:
- www.spaceweather.gc.ca
- www.spaceweather.com

HOW VRS WORKS

How it works – VRS Network



Cell modem
or
Rebroadcast radio

Data Formats

- Cellular Modem – HSPA, HSPA+, GSM/GPRS, CDMA
  - 2-way data transfer directly to VRS server
  - Potentially seamless coverage over large area
  - Subject to limitations and latencies of cellular networks.
  - Telus, Rogers, Bell, MTS
    - CMR
    - CMR+
    - CMRx
    - RTCM 2.xx, 3.x
    - BINEX
    - Leica 4G
    - TPS

Why Cellular

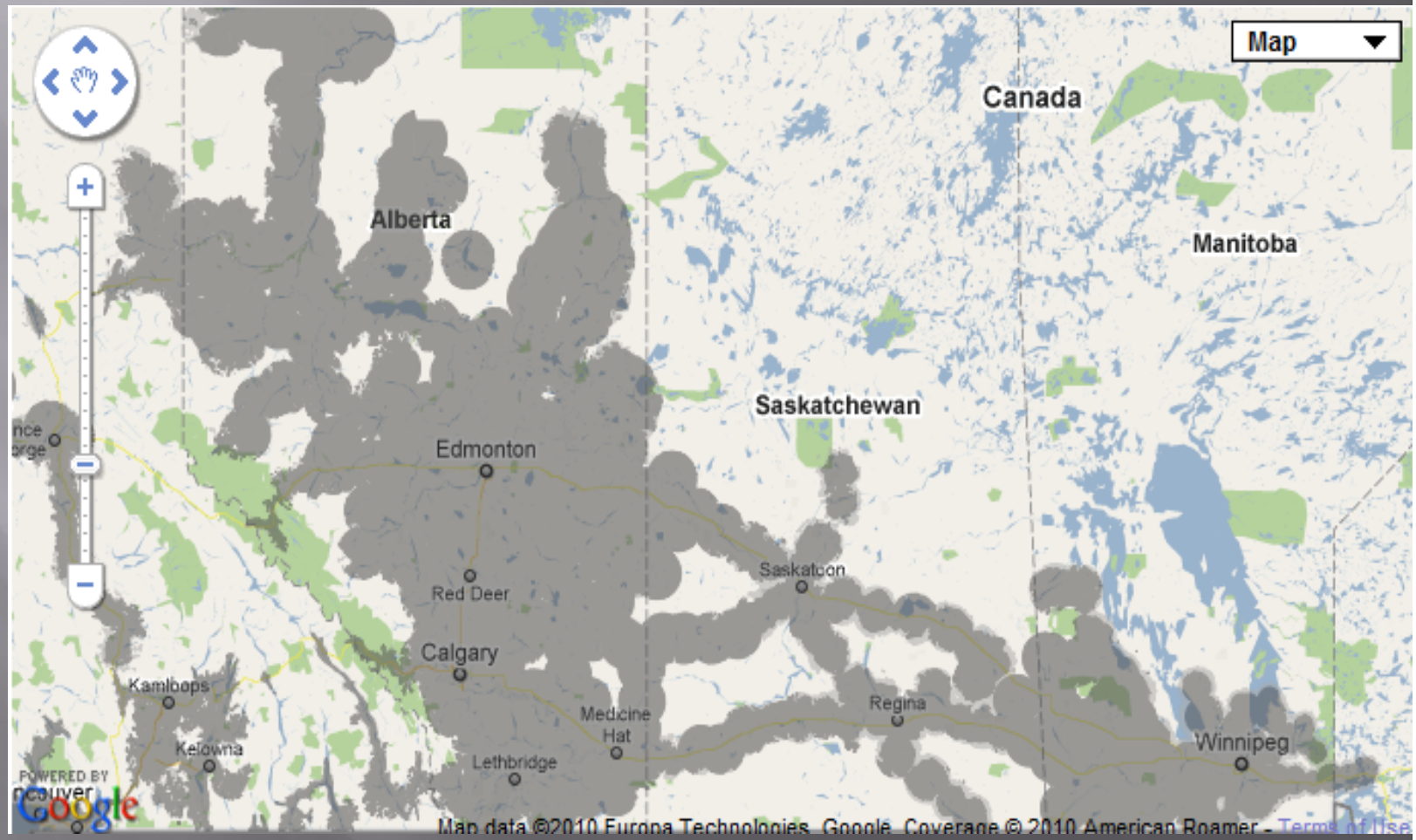
- PRO

- Covers vast areas without repeaters.
- Bi-directional data flow for Connected Surveyor
- Can use RTK bridge in difficult terrain.
- Rarely affected by interference.
- No line of sight.
- Initial cost is less.
- More cellular towers ever year, better technology.

- CON

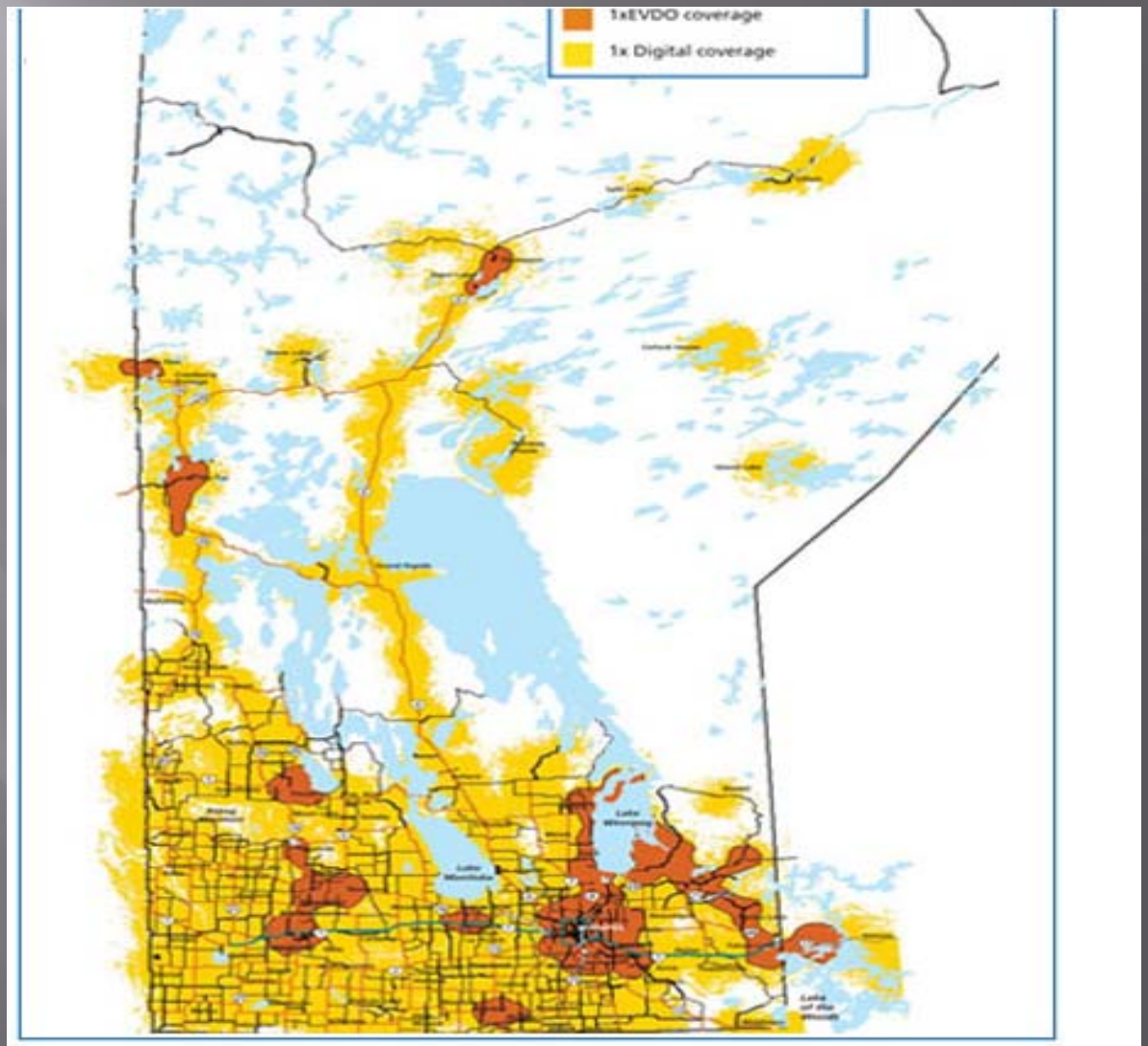
- Coverage!!!!!!
- Need a monthly service plan.

Rogers Coverage



Telus Coverage

MTS



NTRIP

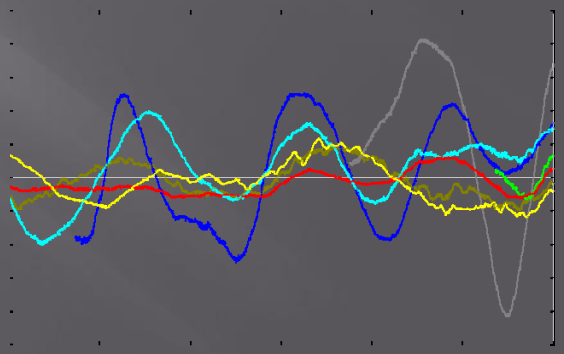
- Networked Transport of RTCM via Internet Protocol
- NTRIP is an RTCM standard designed for transmitting GNSS correction data (e.g. in the RTCM-104 format) or other kinds of GNSS streaming data to stationary or mobile users over the Internet.
- Supports mass usage - hundreds of data streams may be transmitted to up to thousand users.
- Any kind of GNSS data may be transmitted:RTCM / raw data, or any other streamed data (iono-models, ephemeris...
- NTRIP is an Industry standard for GPS manufacturers.
- Authenticates users via username/password.

Benefits of NTRIP usage within an RTK network

- Only one TCP port has to be opened for an unlimited number of user requests for correction data streams.
- There is no direct contact between reference station (NtripServer) and customer (NtripClient), all streams are administered via the NtripCaster → safe data flow.
- Low costs of data transmission, e.g., GPRS, HSPA.
- Low costs of data transmission with RTCM 3.0 due to high compression rate of GNSS data.

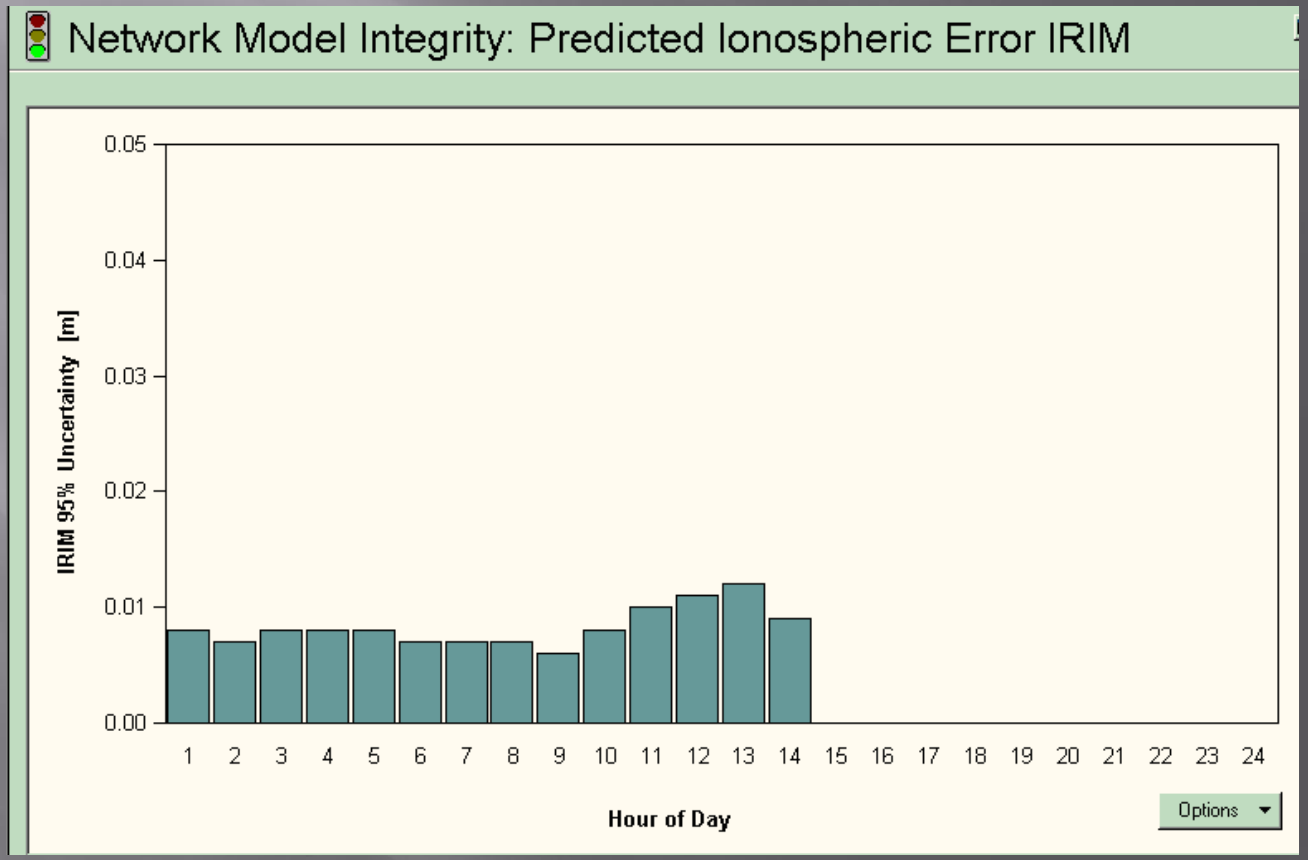
VRS Processing Software

- Integrity monitoring
- Correction for ephemerides errors
- Correction for tropospheric errors
- Correction for ionospheric errors
- Ambiguity resolution
- Delivery of corrections for each user`s location
  - Observed vector to closest base station with localized correction
  - Results in a “zero” baseline for rover
  - Eliminates ppm error
  - Improves initialization times



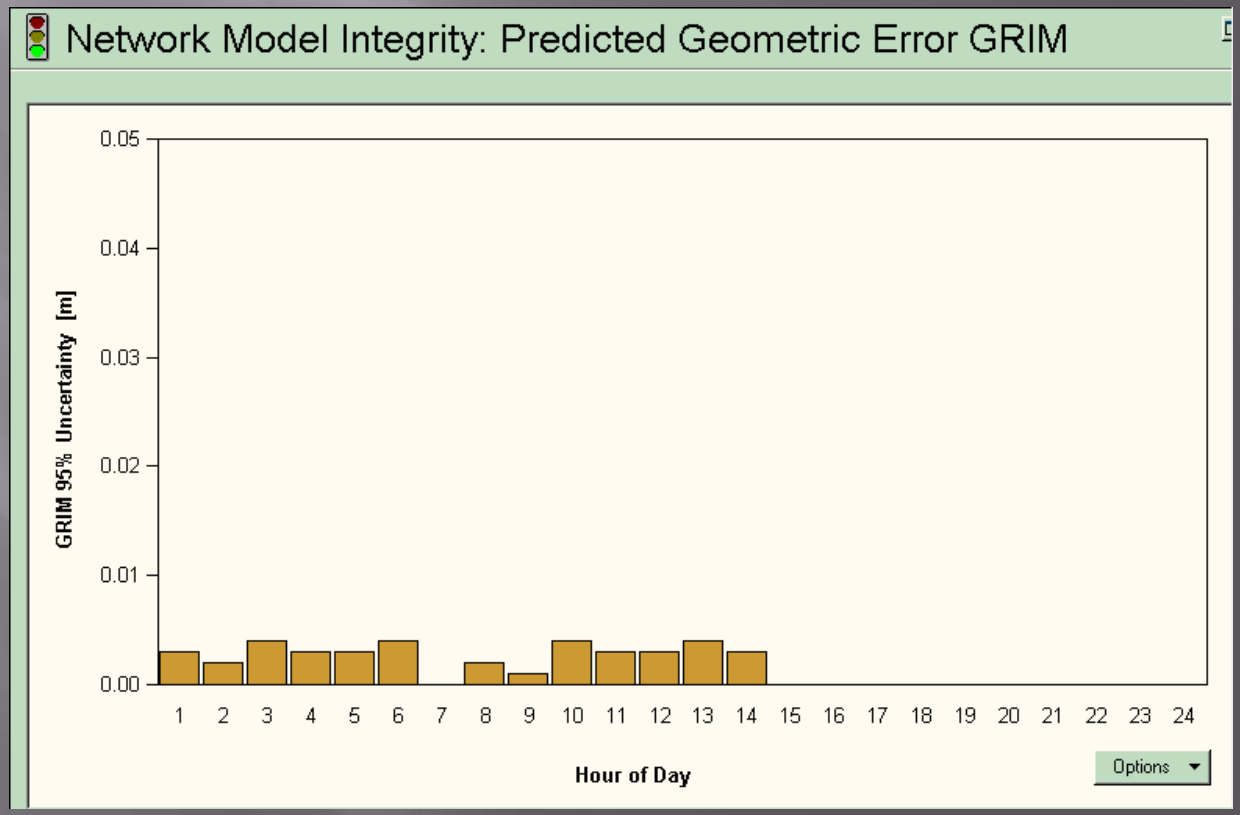
Network Model Integrity

- Ionosphere component

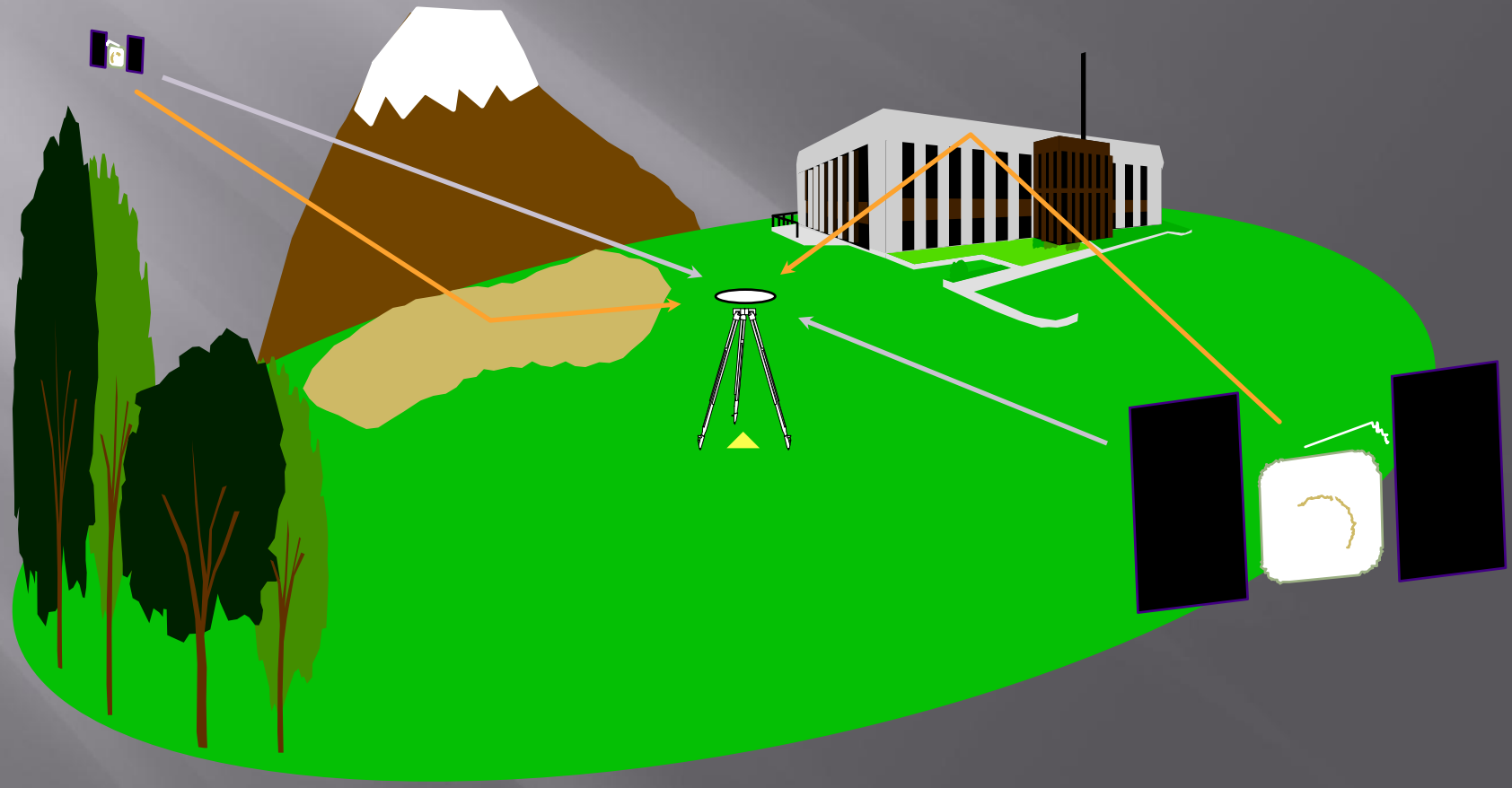


Network Model Integrity

- Geometric component
  - Satellite corrections and troposphere

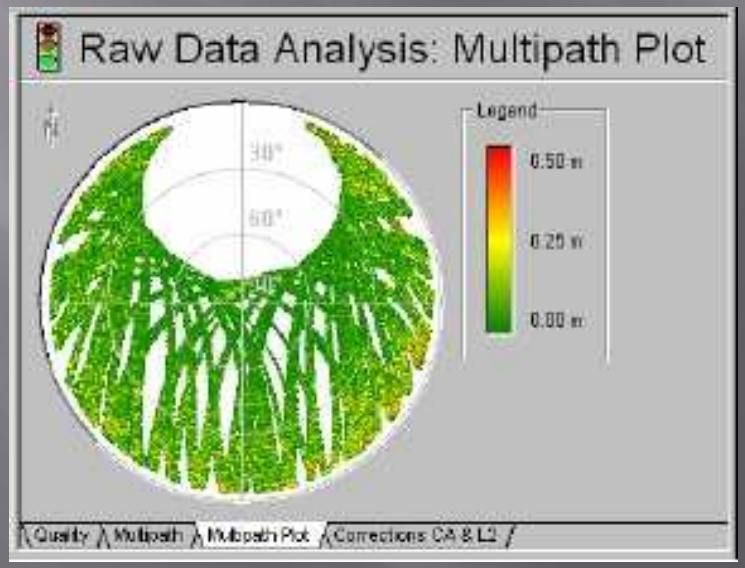


Multipath



Quality Control – Multipath

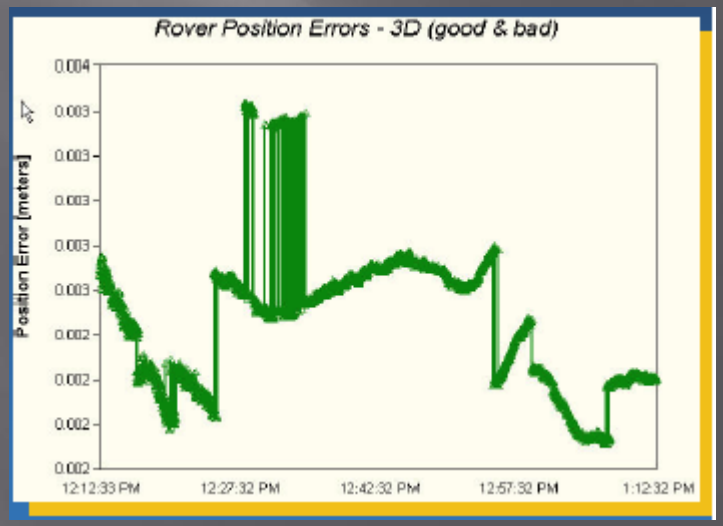
- *Quality*
- *Multipath Plot*
- *Corrections CA and L2*



Raw Data Analysis Quality Checks	
Bad Satellite ID	Code difference bad
Bad SNR L1	No ephemeris
Bad SNR L2	SPP residual bad
LLI data bad on L1	SPP position bad
LLI data bad on L2	Data gap too long
L1-phase bad	Too few data
L2-phase bad	Unresolved cycle slip
L1-code bad	Resolved cycle slip
L2-code bad	Continued cycle slip

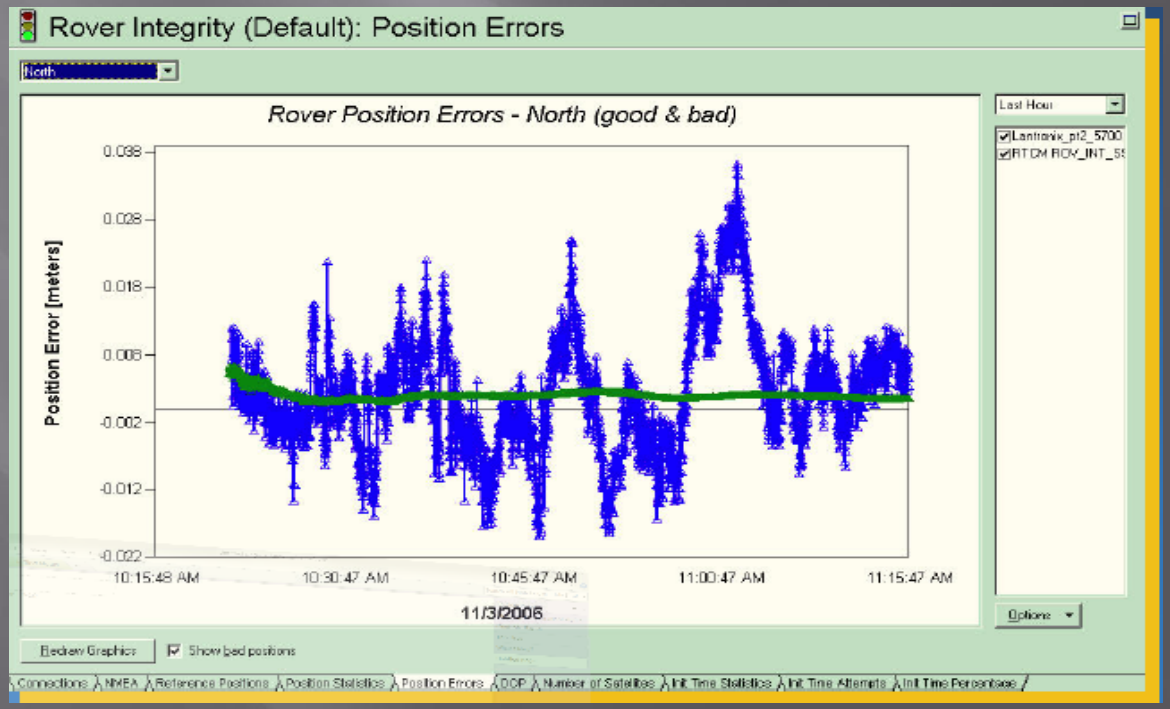
Rover Integrity Fundamentals

- What is it?
  - A permanently installed rover using your network solution to initialize and provide statistics
  - Compares a keyed in position to a calculated rover position
  - Includes statistics feedback in real time, daily reports and alarms



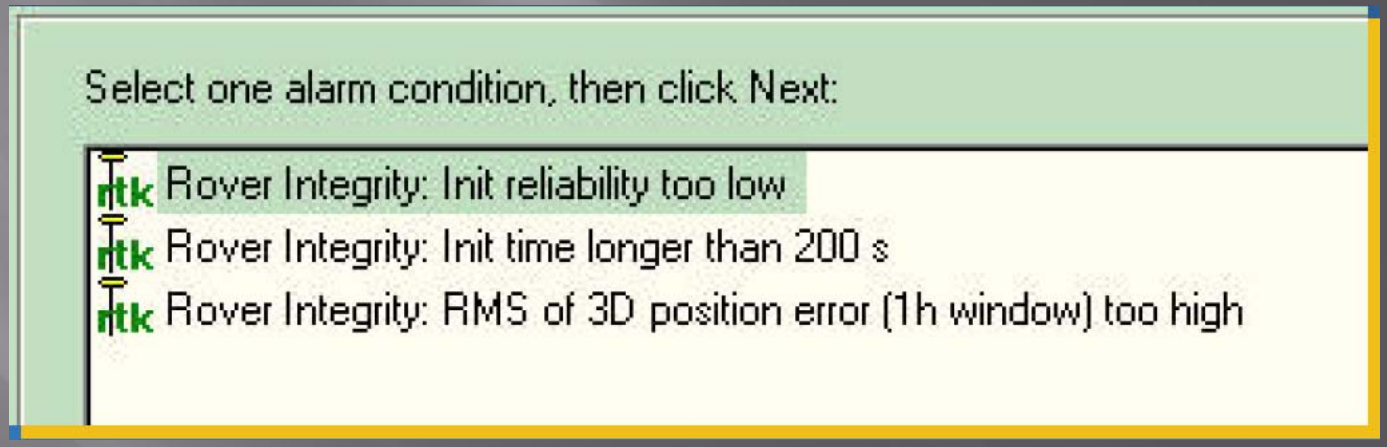
Rover Integrity Fundamentals

- Why do it?
  - Provides COMPLETE CONFIDENCE in our network solution
  - Excellent for network troubleshooting
  - Allows you to complete the data cycle; see your network solution applied at your permanent rover



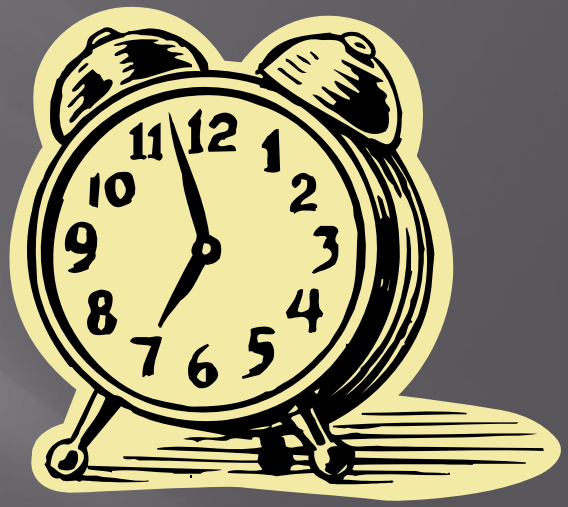
Alarms

- Alarms are set so that the administrator is alerted to any unusual activity.
- Steps are taken to resolve the issue immediately (probably would not know this from a single base station)



Integrity - Alarming

- **Alarming provides notification of user-defined events**
- Alarm Methods:
  - *Issue alarm sound*
  - *Send e-mail*
  - *Send modem command*
  - *Send boot command to power switch*
  - *Run batch file process*



Quality Control – Coordinate Monitor

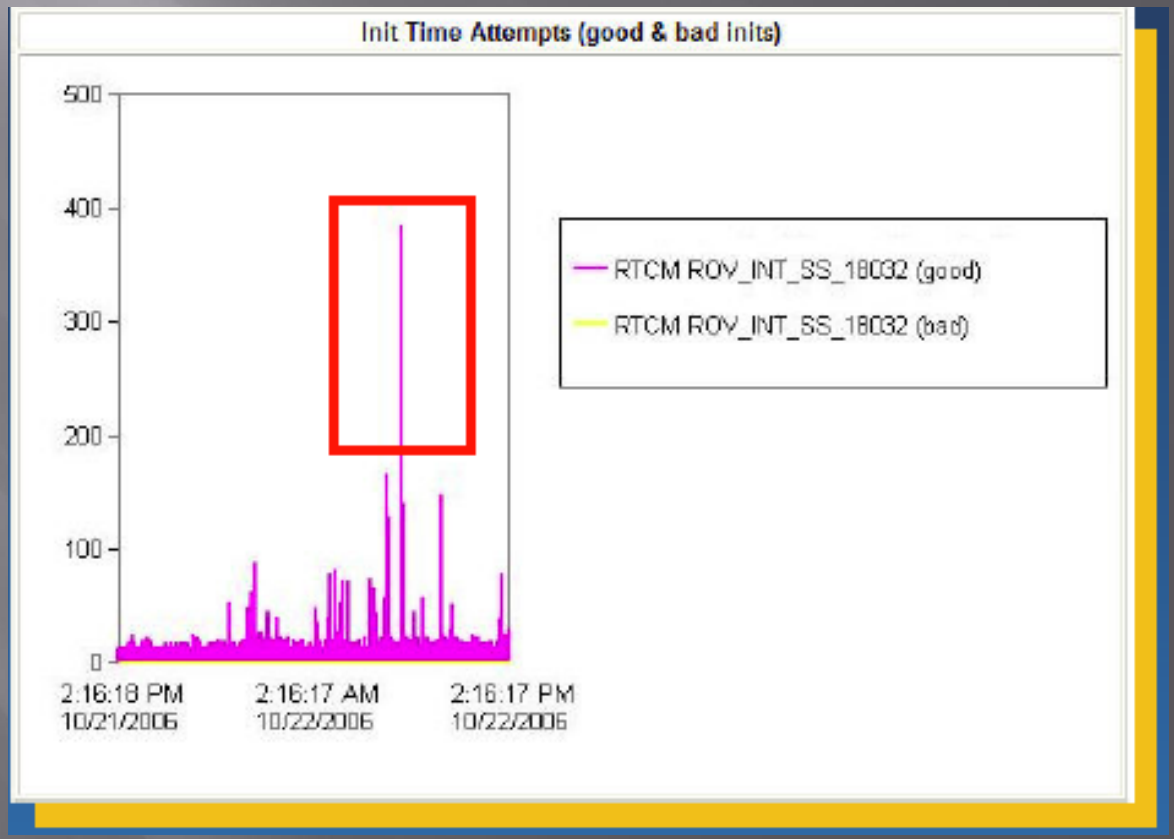
- Coordinate Monitor performs a continuous analysis of the reference station coordinates
  - Independent processor
  - Control of coordinate quality
  - Near Real Time solution
- This allows the system to countercheck for errors in defined coordinates, wrong definition of antenna heights or antenna types.

Quality Control – Raw Data Analysis

- Analyses the consistency of dual frequency data for each satellite.
- Detects receiver errors
  - Example:
    - Data drifts
    - Cycle-slips
    - Generates pseudo-range and range rate corrections.
- The module tries to correct any errors received.
- Uncorrected data or bad data is removed.

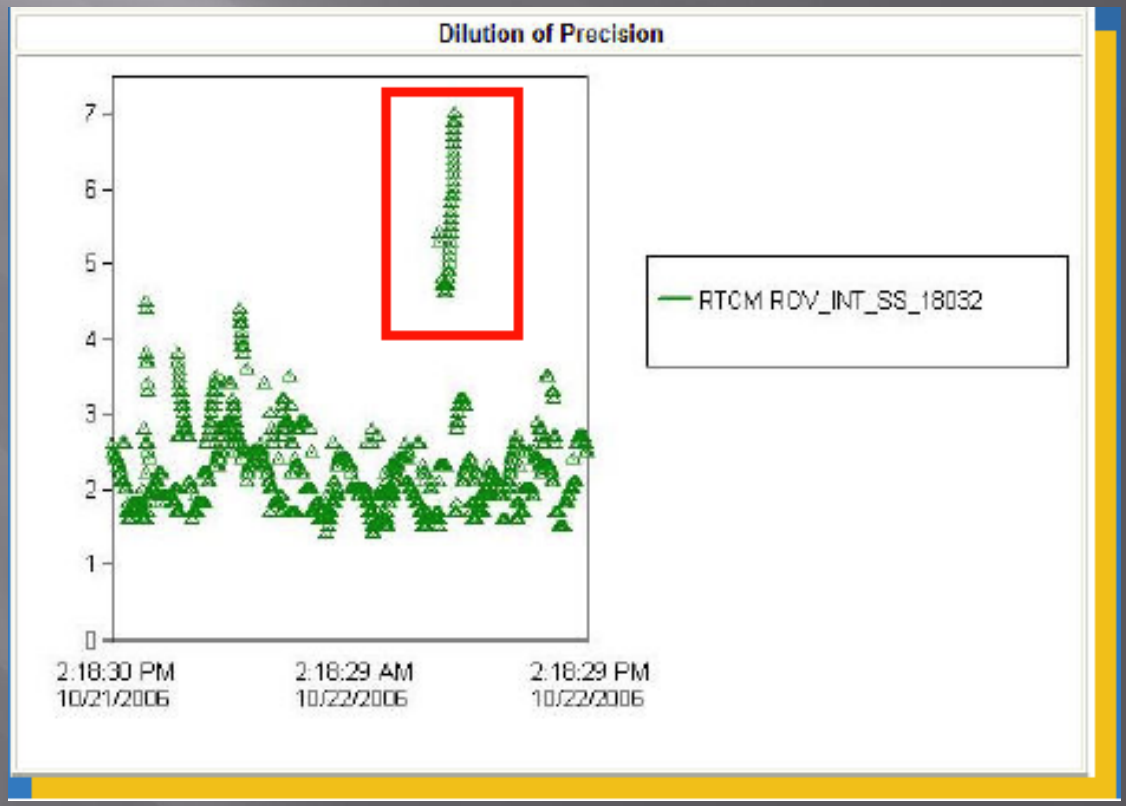
Initialization Attempts

- Initialization time statistics



Initialization

- PDOP spike



Initialization cont'd…

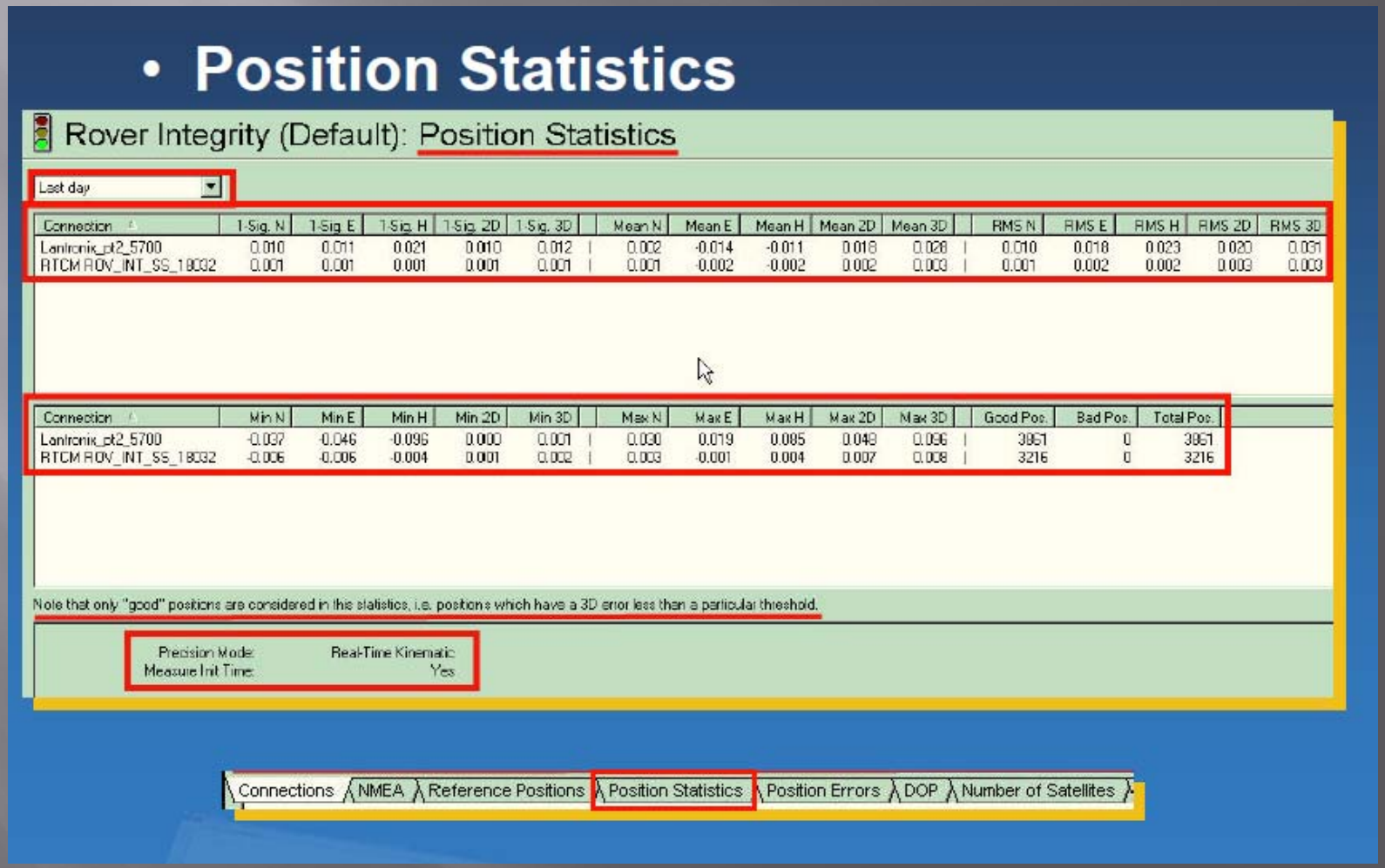
- Pattern in data
  - Check site for multi-path
- Consistent offsets
  - Check reference position
- Rover specs met?
- Data Complete?
  - Check network connectivity
- Re-initializing rover without active re-init?
  - Check network connectivity

Operation

- Feedback tools provide:
  - Review of Rover Integrity real-time data
  - Reports for stored (usually daily) data
  - View NMEA log file for a record of all received positions
  - View position errors file for summary of deltas between received NMEA and reference position
  - Position errors
  - DOP
  - Number of Satellites
  - Initialization attempts, Statistics, Initialization time percentage

Operation

- **Position Statistics**



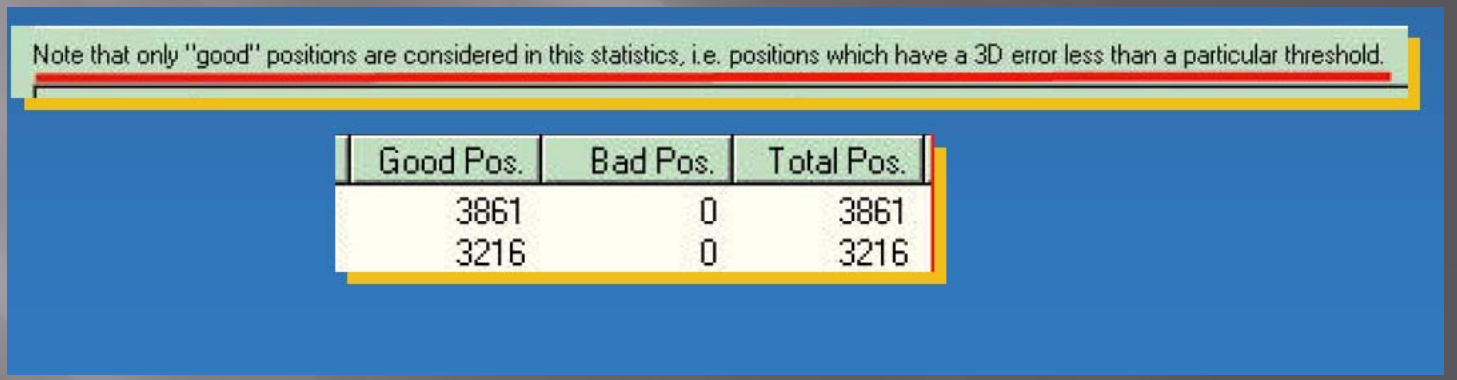
Operation

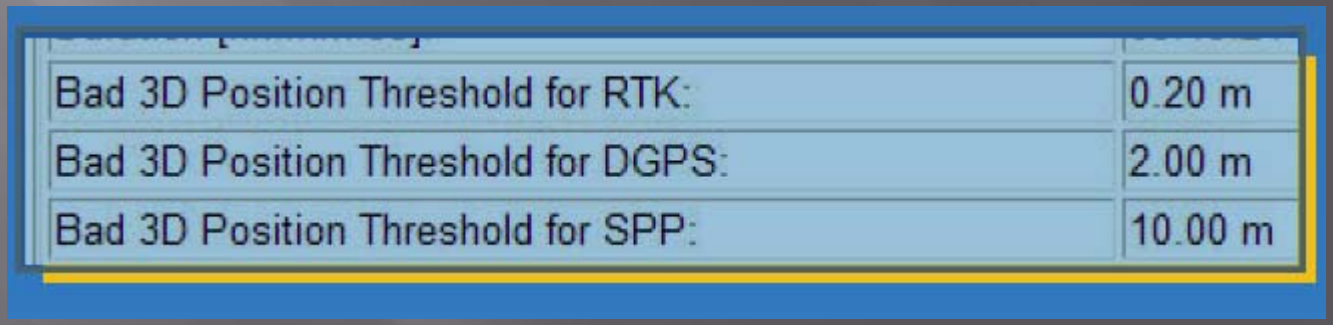
- Position Statistics
  - RMS = Accuracy
  - Accuracy equals closeness to truth (based on our keyed in reference position)
  - Susceptible to bad reference position
    - Check for consistent offsets

RMS N	RMS E	RMS H	RMS 2D	RMS 3D
0.010	0.018	0.023	0.020	0.031
0.001	0.002	0.002	0.003	0.003

Operation

- Position Statistics
  - What is a good position? Must be <20cm from reference position to be graphed for RTK quality reporting.
  - Threshold values





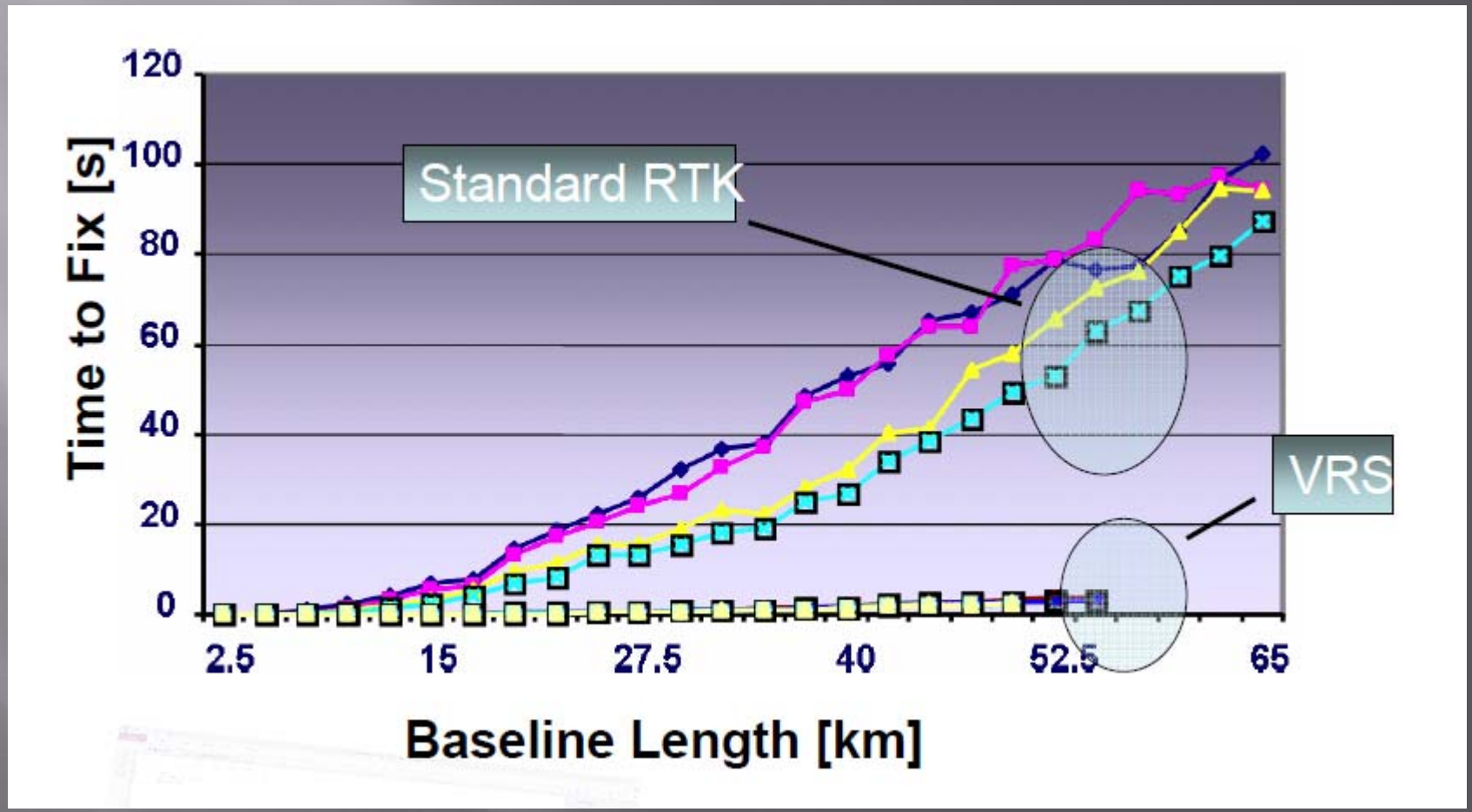
Challenges for Network RTK

- Different Manufacturer GPS receivers
- Receivers with different tracking capabilities

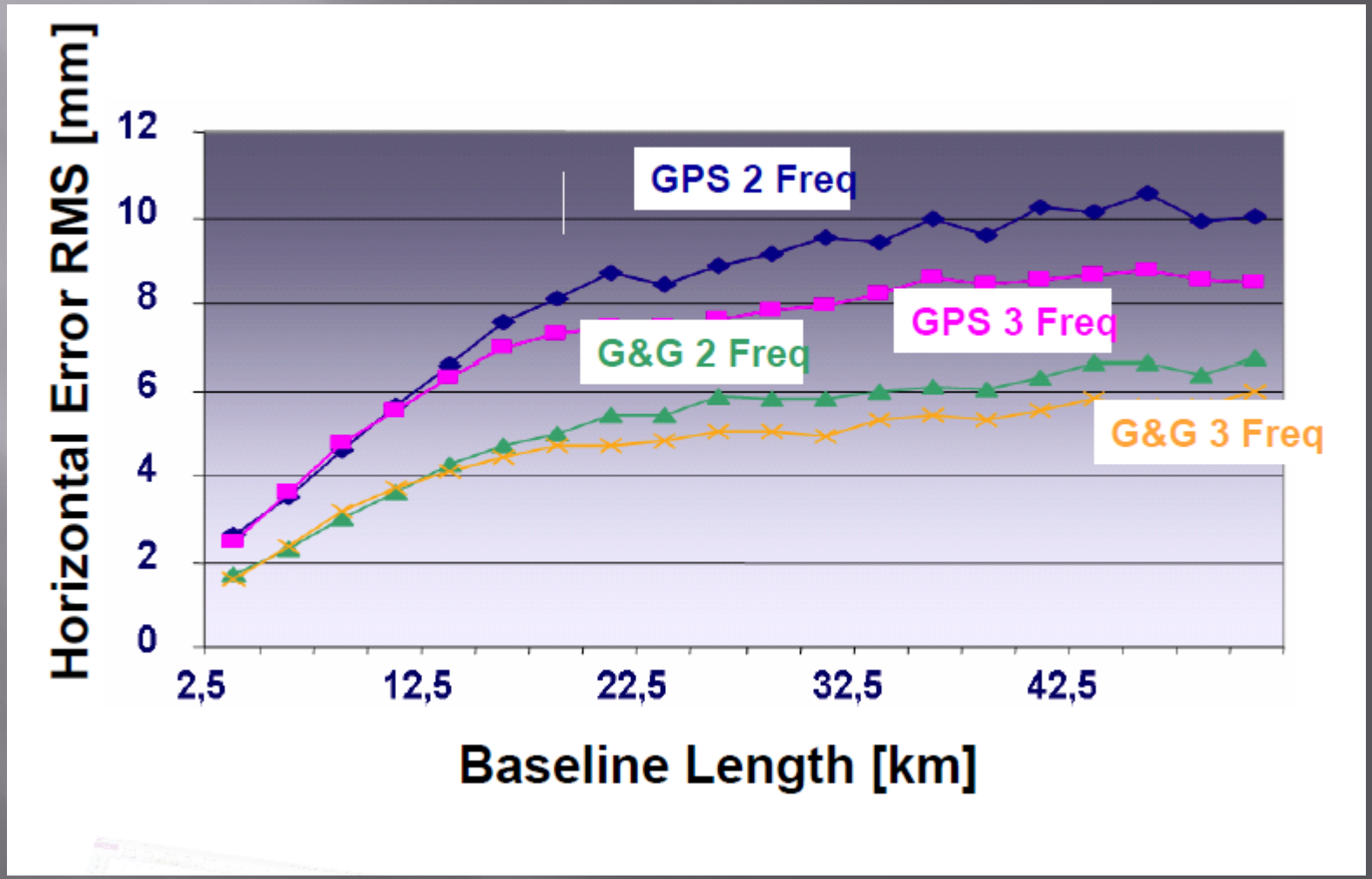
  - Network has to support all rover types
  - VRS Server software must be flexible, complexity will increase

COMPARISON

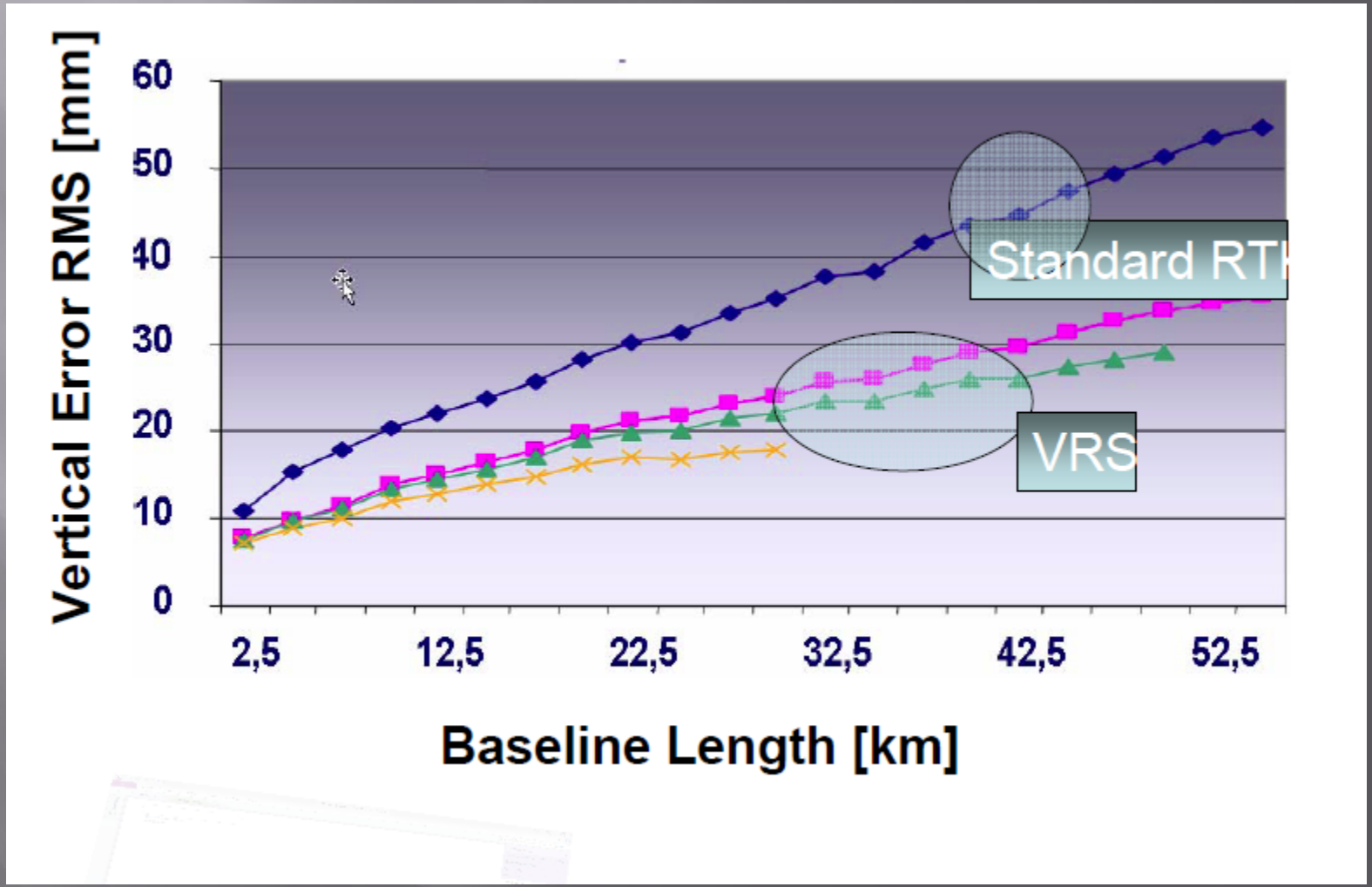
Time to Fix (TTF)



Horizontal Accuracy VRS



Vertical Accuracy



Conclusions

- New signals will improve RTK and Network RTK (VRS) solutions
- GNSS modernization will not obsolete VRS
- VRS greatly improves vertical accuracy
- Longer distances between stations
- VRS will be the tool to improve efficiency and increase accuracy for surveyors.

  - VRS is accurate to *1cm horizontal, 2cm vertical accuracy anywhere in the network.*

Questions?