National Geodetic Survey

REAL-TIME POSITIONING GUIDELINES FOR THE INTERNATIONAL COMMUNITY-- THE ROLE OF FIG

FIG WORKWEEK
TS 4C, 17JUNE2008
STOCKHOLM, SWEDEN

Bill Henning, Senior Geodesist, PLS.

National Oceanic and Atmospheric Administration

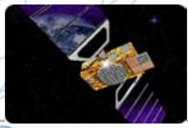
National Geodetic

DYNAMIC RT TECHNOLOGY

GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)

POTENTIAL FUTURE DEVELOPMENTS(2005 – 2017?)
GPS MODERNIZATION – BLOCK IIF & III
GLONASS ENHANCEMENTS (K & M)
EUROPEAN UNION - GALILEO
CHINA – COMPASS
INDIA, JAPAN -?

115+ Satellites
Second and Third Civil Frequency - GPS
No Signal Encryption - GLONASS & GALILEO
More Robust Signal Transmissions
Real-Time Unaugmented 1 Meter (or better!) Accuracy

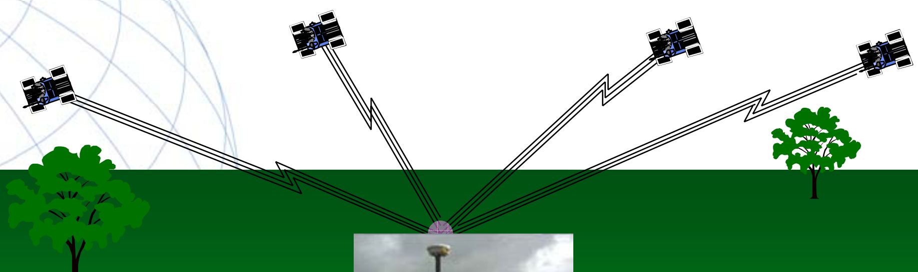


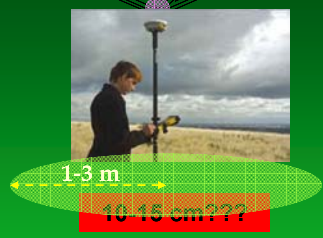
+ BETTER COMMUNICATION COVERAGE & TECHNOLOGY

National Oceanic and Atmospheric Administration

National Geodetic Survey

STANDALONE POSITIONING: BY 2017?





UERE - 2008

Error	Value
Ionosphere	4.0 meters
Clock	2.1 meters
Ephemeris	2.1 meters
Troposphere	0.7 meters
Receiver	0.5 meters
Multipath	1.0 meter
Total	**10.4 meters**

- Civil Code on L1
- Civil Code on L2
- New Code on L5

BETTER RESISTANCE TO INTERFERENCE

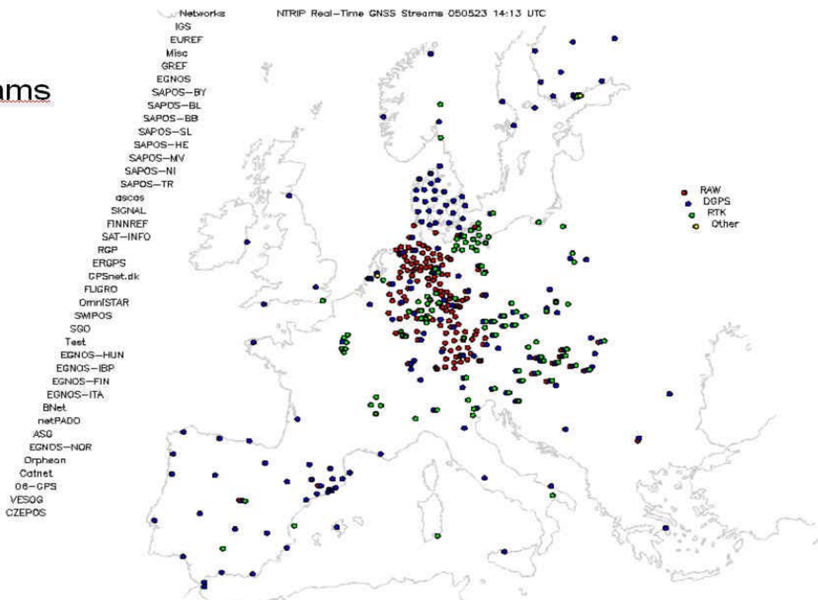
FASTER AMBIGUITY RESOLUTION

National Geodetic Survey

NTRIP STREAMS- EUROPE

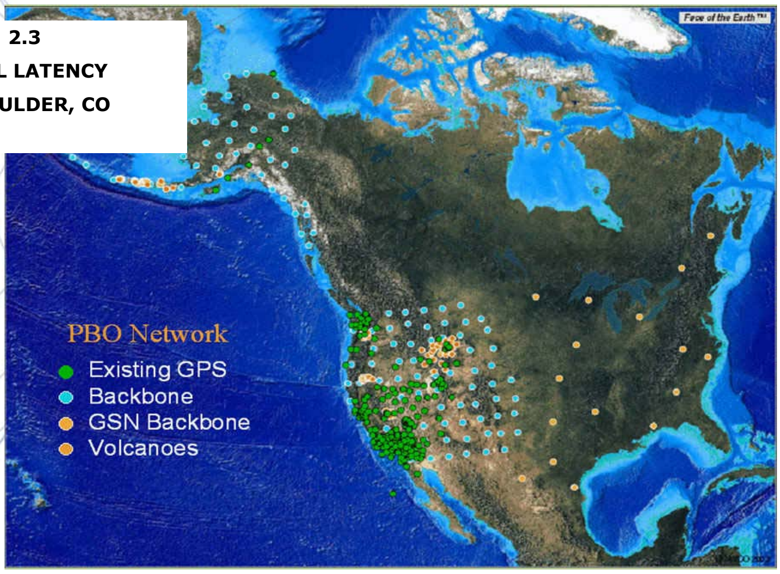
Bundesamt für Kartographie und Geodäsie

Ntrip Streams Europe

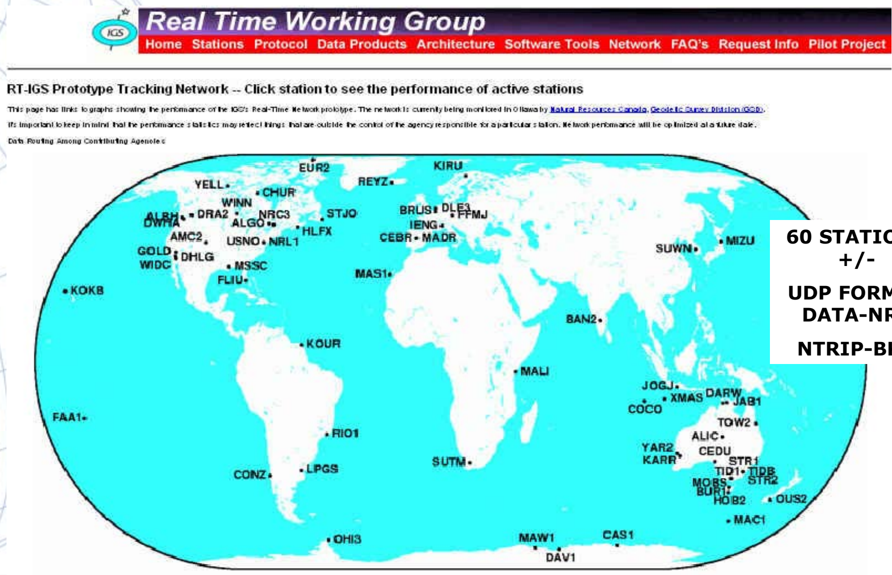


PBO STATIONS

- BINEX & RTCM 2.3
- 2 – 2.25 TOTAL LATENCY
- SERVER IN BOULDER, CO
- 60 STATIONS



IGS RT STATIONS



60 STATIONS
+/-

UDP FORMAT
DATA-NRC

NTRIP-BKG

CURRENT NGS ACTIVITY IN SUPPORT OF REAL-TIME POSITIONING

OVERALL PROGRAM OBJECTIVE

- Ensure that geodetic issues are adequately addressed in operation and use of real-time positioning systems

CHANGE IN ACCESSING THE NSRS BY PASSIVE TO ACTIVE MONUMENTATION

EXAMPLE: GNSS DERIVED HEIGHTS

PASSIVE

- NOS-NGS 58 WITH DRAFT ORTHO GUIDELINES- 0.05 m TO NSRS, 0.02 m LOCAL
- DGPS – 15 SECONDS, 0.5 TO 2 m

ACTIVE

- OPUS > 4 HRS = 0.02 M (h), 0.05 (H)
- CORS- SAME AS OPUS
- OPUS-RS 15 MINUTES =0.10 m
- SINGLE BASE RTK- "IT DEPENDS!" 5 SECONDS (better than 0.03 m expected)
- RTN – "IT DEPENDS!" 5 SECONDS (better than 0.04 m expected)

STATIC: 5 1/2 HOURS - HARN; 30-45 MINUTES NETWORK

STATIC: 2-4 HOURS; 10-30 MINUTES

REAL TIME: 5 SECONDS - 3 MINUTES

RT ACCESS TO THE NSRS

- GUIDELINES, SPECS, STANDARDS
  - √ SINGLE-BASE USER
  - RTN PLANNING & NETWORK DESIGN
  - RTN CONSTRUCTION/SITE EVALUATION
  - RTN ADMINISTRATIVE
  - RTN USER

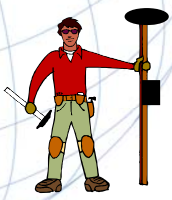
  } **RTN TEAM – ADVISORS AND PARTNERS**

- STREAMING DATA FROM THE FOUNDATION CORS (**HEADQUARTERS RT TEAM**)
- REFERENCE STATION & USER POSITION MONITORING, DATA ARCHIVING, 60 DAY PLOTS = NGS 'VERIFICATION'

National Geodetic Survey

THE TWO DIRECTIONS OF REAL-TIME POSITIONING

I. TOP DOWN: Overall Administrator's viewpoint- Alignment to the NSRS, coordinates, adjustments, Network spacing, Site requirements, Communication issues, Personnel, Cost/Benefit analysis, $$$$, Partners



II. USER UP: Best methods- Field techniques, GNSS knowledge, Knowing datum requirements, Knowing accuracy requirements, Calibrations, Applications, Data management

CLASSICAL RT..........................NETWORK RT (RTN)

National Oceanic and Atmospheric Administration

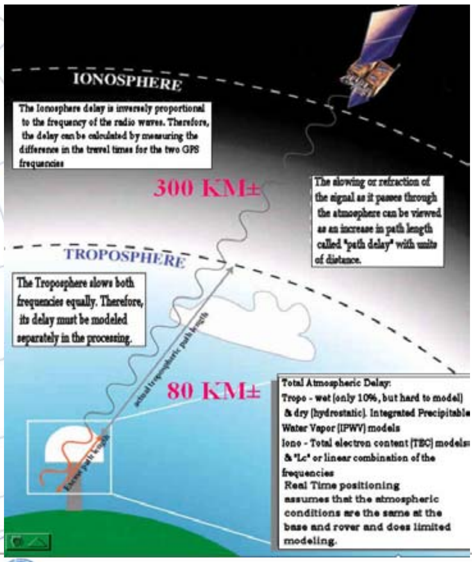
USER EXPERTISE MEANS CONSIDERING:

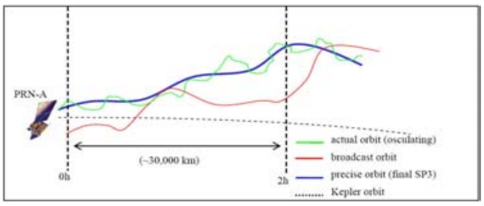
- Multipath
- Position Dilution of Precision (PDOP)
- Baseline Root Mean Square (RMS)
- Number of satellites
- Elevation mask (or cut-off angle)
- Base accuracy- datum level, local level
- Base security
- Redundancy, redundancy, redundancy
- Part(s) Per Million Error (ppm)– iono, tropo models, orbit 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)
- Float and Fixed Solutions
- Carrier phase
- Code phase
- VHF/UHF radio communication
- CDMA/SIM/Cellular TCP/IP communication
- WGS 84 versus NAD 83, or other local datums
- GPS, GLONASS, Galileo, Compass Constellations

Natior

National Geodetic Survey

ATMOSPHERIC AND ORBIT ERROR SOURCES





GRAPHIC SOURCE:

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.

National Oceanic and Atmospheric Administration

National Geodetic Survey

WHY SINGLE-BASE?

-ACCOMMODATE LEGACY USERS

- CLOSEST BASE NETWORKS

-AREAS WITH NO CELL COVERAGE

- PROJECT SITE APPLICATIONS, SUCH AS MACHINE CONTROL

http://www.ngs.noaa.gov/

NATIONAL GEODETIC SURVEY
USER GUIDELINES
FOR CLASSICAL
REAL TIME GNSS POSITIONING

DRAFT

v. 2.0 April 2008

William Henning, lead author

WHY EMPIRICAL?

-PLETHORA OF VARIABLES

-TIMELINESS

-PORT TO RTN USERS

-DYNAMIC NATURE OF RT POSITIONING

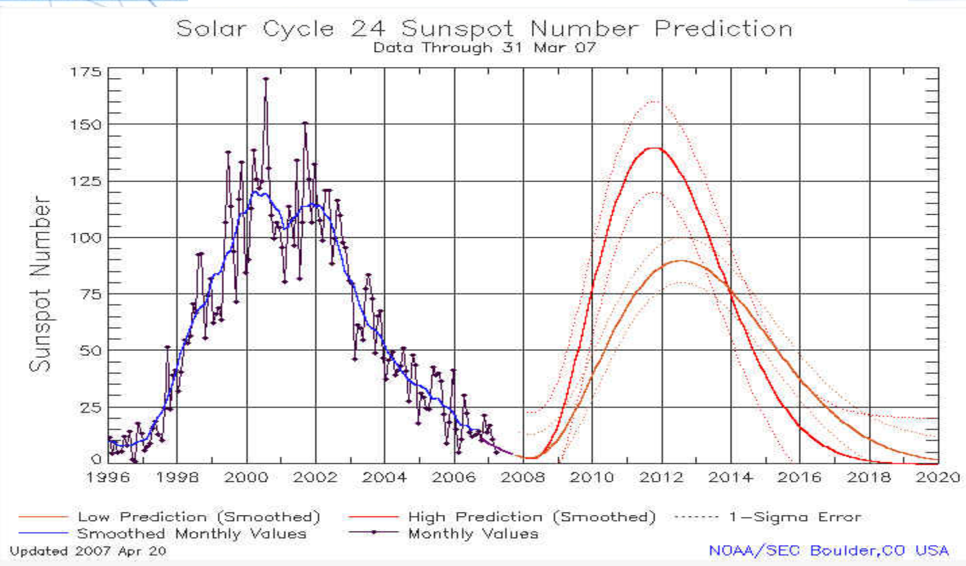
…spheric Administration

RT SINGLE-BASE ACCURACY CLASSES

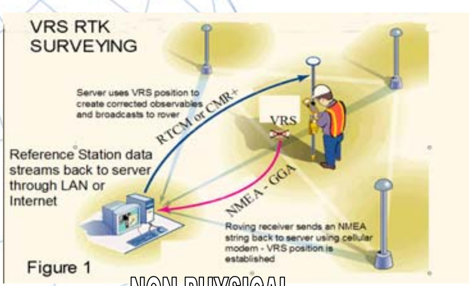
ACCURACY CLASS SUMMARY TABLE

	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 VETLANDS GIS POPULATION MAPPING ENVIRONMENTAL

IONOSPHERIC EFFECTS ON POSITIONING



RTN APPLICATIONS- INTERPOLATION AND MODELING OF ERROR FACTORS



NON-PHYSICAL REFERENCE STATION

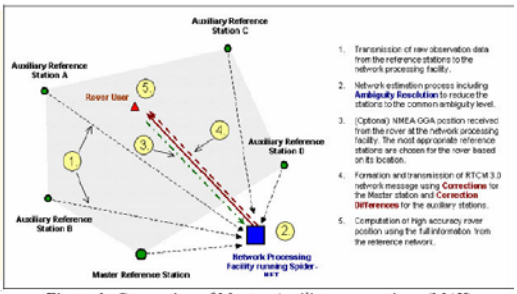
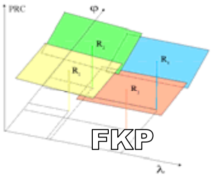


Figure 1: Generation of Master-Auxiliary corrections (MAX)

MASTER-AUXILIARY



FKP

EXAMPLES OF RTN ADMINISTRATORS IN THE USA

- ACADEMIC/SCIENTIFIC
- SPATIAL REFERENCE CENTERS
- VARIOUS DOTS
- COUNTY } **RAPIDLY GROWING**
- CITY
- GEODETIC SURVEYS
- MANUFACTURER
- VENDOR NETWORKS
- AGRICULTURE
- MA & PA NETWORKS

National Geodetic Survey

REAL TIME NETWORKS (RTN)

?

- **PERHAPS MORE THAN 75 RTN EXIST IN THE USA WITH MANY IN THE PLANNING STAGES**
- **HOW ARE THEY ESTABLISHED?**
- **HOW ARE THEIR COORDINATES COMPUTED? ARE THEY CONSISTENT?**
- **HOW IS THE NETWORK ADJUSTED?**
- **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?**

National Oceanic and Atmospheric Administration

Guidelines for Operating a Real-Time GNSS Network CHAPTER ONE -Achieving Consistency Among Positional Coordinates and Velocities

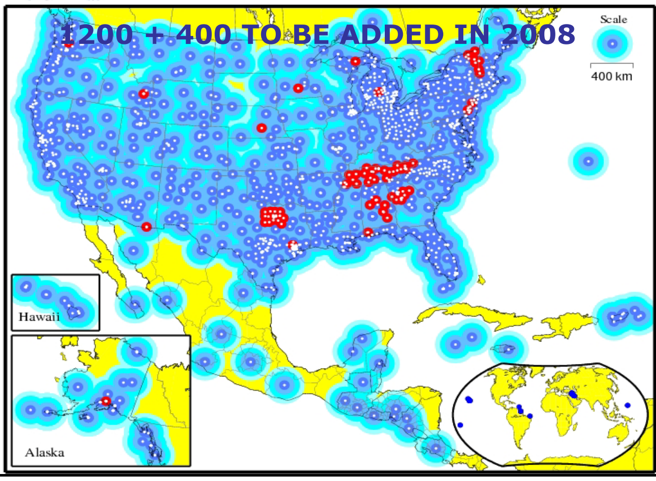
- ITRF 2000 or NAD 83
  3 recommendations:
- #1 Include a subnetwork of the RTN into the National CORS network.
- #2 For each reference station contained in the RTN, adopt values for its 3-dimensional positional coordinates (at a selected epoch date) and a velocity that are consistent with corresponding values adopted by NGS for reference stations in the National CORS network.
- #3 For each reference station in the RTN, use the Online Positioning User Service (OPUS) at http://www.ngs.noaa.gov/OPUS/ to test for the continued consistency of its adopted positional coordinates and velocity on a daily basis, and revise the station's adopted coordinates and/or velocity if the tests reveal a need to do so.

National Oceanic and Atmospheric Administration

Supporting New Products

Real time - essential that CORS/NGS supports this activity.

- TO DO: compute ultra-rapid orbits, QC coordinates, provide data-streams. Currently CORS only supports 6 sites with limited data-streams

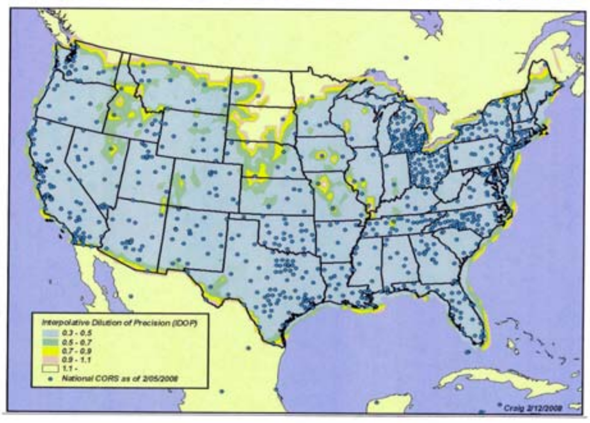


GNSS sites

IDOP

OPUS-RS Coverage

Interpolative Dilution of Precision (IDOP) Values



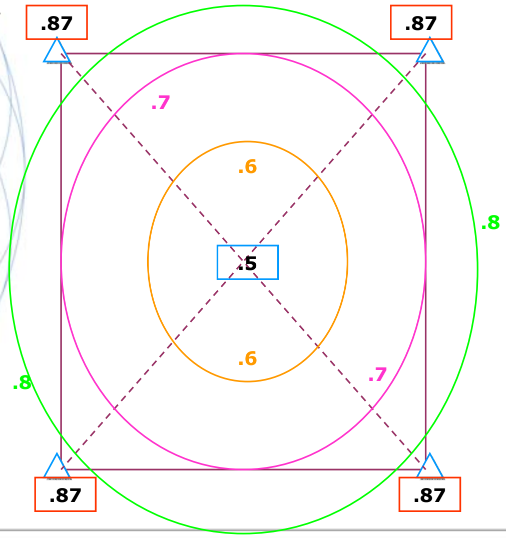
IDOP + SCALE COULD CORRELATE TO ACCURACY

IDOP VALUES – 4 CORS EXAMPLE

BEST IDOP = $\frac{1}{\sqrt{N}}$

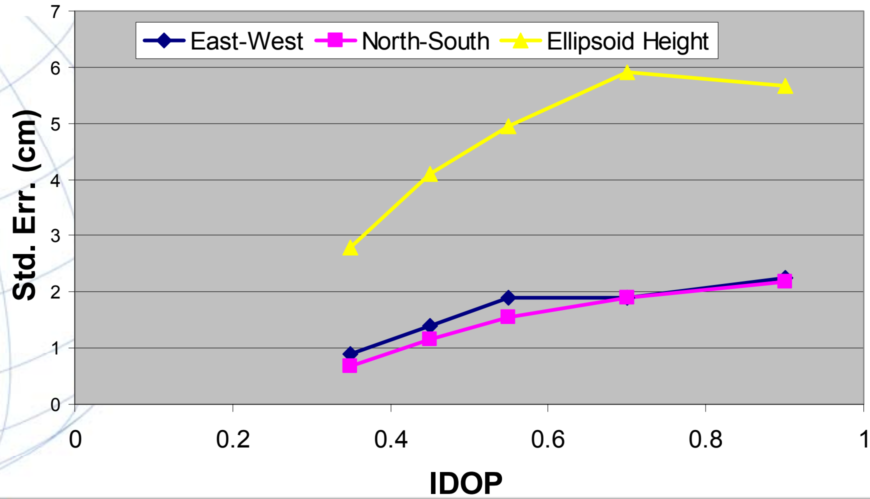
THEREFORE, WITH 9 CORS, THE IDOP AT THE CENTROID WOULD BE .33, WITH 4 CORS IT WOULD BE .5 AT THE CENTROID

ADDITION OF RMS OF DISTANCE TO CORS CONTRIBUTING TO THE SOLUTION GIVES FINAL UNITLESS NUMBER



"IDOP" WILL BE THE SUBJECT OF A FORTHCOMING PAPER BY DRS. RICHARD SNAY, TOM SOLER AND CHARLES SCHWARZ

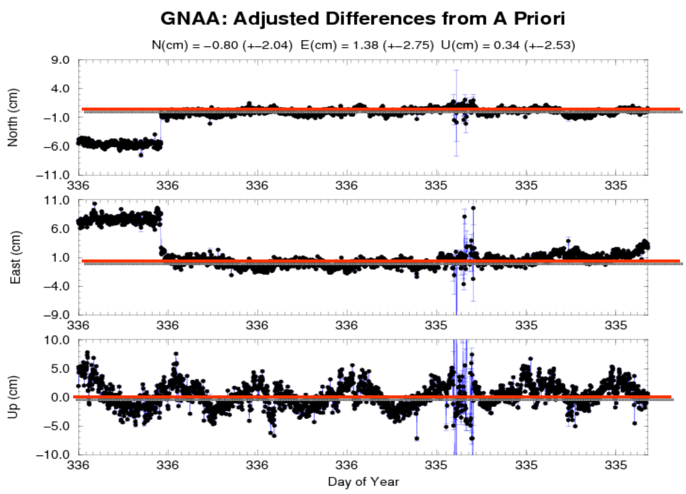
OPUS-RS Accuracy for 15-minute data sets



HOW ACCURATE ARE THE NATIONAL CORS?

- EVALUATED TO 1 CM H, 2 CM V RELATIVE TO ITRF 2000 (2 CM/ 4 CM RELATIVE TO NAD 83 CHANGES COORDINATES)
- DAILY ADJUSTMENTS CONSTRAINED TO 5 CORS
- SEASONAL VARIATIONS
- DAILY VARIATIONS SEEN FROM OPUS-RS
- OCEAN & SOLID EARTH LOADING
- VELOCITIES FROM HTDP VS TIME SERIES

GNAA- ALASKA CORS- DENALI QUAKE + SEASONAL VERTICAL MOVEMENT



NGS Real Time Stream Team

Product Manager

Richard Snay

Outreach and User Relations

Bill Henning

Pam Fromhertz

CORS Data Streams

Charlie Schwarz

Neil Weston

Giovanni Sella

IT Team

Bruce Sailer

Hong Chen

Sky Chaleff

ISO GUIDELINES

- The Int … 172, S … for "GN … mmittee … esting … (RTK)"
- http:// … htm?cs … detail.
- "…..are … evaluat …

DRAFT INTERNATIONAL STANDARD ISO/DIS 17123-8

ISO/TC 172/SC 6 Secretariat: SNV

Voting begins on: 2006-08-18 Voting terminates on: 2007-01-18

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Optics and optical instruments — Field procedures for testing geodetic and surveying instruments —

Part 8:
GNSS field measurement systems in real-time kinematic (RTK)

Optique et instruments d'optique — Méthodes d'essai sur site pour les instruments géodésiques et d'observation —

Partie 8: Systèmes de mesure GNSS sur site en temps réel cinématique

ICS 17.180.30

ISO RT GNSS EQUIPMENT TEST PROCEDURES

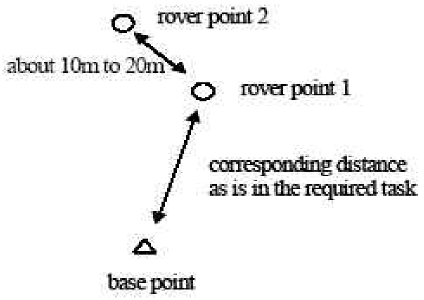


Figure 1 — Configuration of the field test network

SERIES OF 5 LOCATIONS AT ROVER POINTS 1 & 2, SPACED 5 MINUTES APART

***SIMPLIFIED TEST*:**

- 1 SERIES COMPARED TO INDEPENDENTLY OBTAINED MEASUREMENTS OF DISTANCE (SPACING) AND HEIGHT ≤ 3 mm

***FULL TEST*:**

-3 SERIES COMPARED TO INDEPENDENTLY OBTAINED MEASUREMENTS OF DISTANCE (SPACING) AND HEIGHT ≤ 3 mm

- DEVELOP STATISTICAL TESTS VIA LEAST SQUARES METHODS

All measurements must fall within the manufacturer'ss' deviation tolerances for horizontal and vertical precision (or if these are unavailable, 15 mm horizontal and 25 mm vertical). Temperature and general weather conditions are noted by the observer.

FIG COMMISSION 5

- The Commission 5 delegates must become familiar with the ISO/TC172 standards as a building block.
- National survey organizations, such as NGS, should draft their best practices for real-time positioning – both for classical single-base and RTN methodologies.
- Commission 5, workgroup 5.1, in charge of standards, quality assurance and calibration, should be tasked with compiling these best practices and preparing a summary for review by the international surveying community.

National Geodetic Survey

NGS CONTACTS

- WILLIAM.HENNING@NOAA.GOV
  REAL-TIME POSITIONING
- DAVE.DOYLE@NOAA.GOV
  FIG ISSUES, ALL NGS FUNCTIONS, DATUMS, COORDINATE SYSTEMS
- DAVE.ZILKOSKI@NOAA.GOV
  DIRECTION OF THE NGS

National Oceanic and Atmospheric Administration