# Interpreting OPUS-S and RS Results

NATIONAL GEODETIC SURVEY

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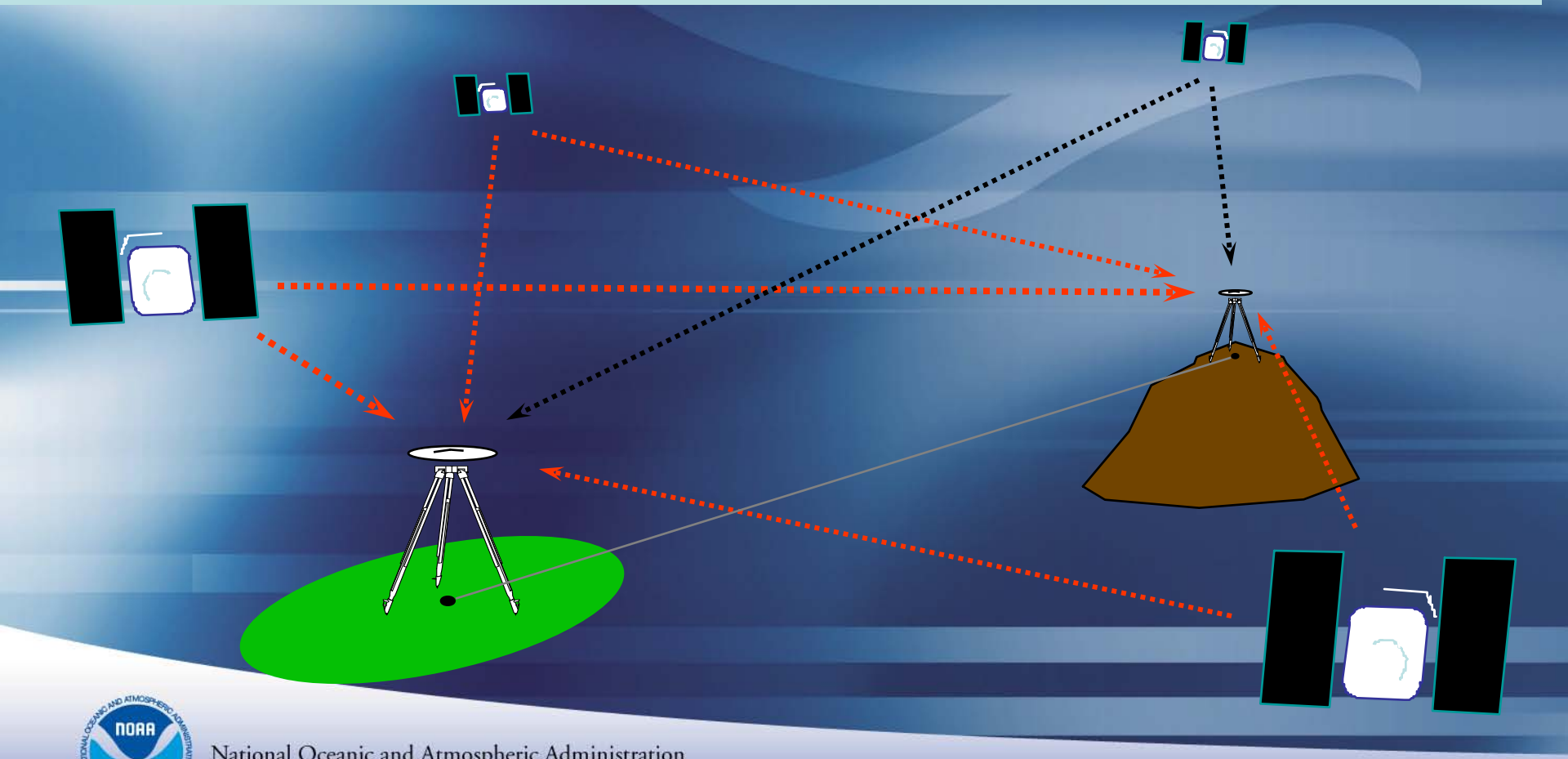


National Oceanic and Atmospheric Administration

# OPUS Guidelines

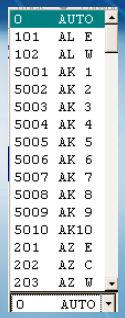
- Dual-frequency data (L1/L2)
- Minimum 2 hrs of data (maximum 48—only cross midnight once)
- No kinematic or L1 only (OPUS-GIS Proposed)
- No GLONASS

Accurate height requires:

- correct antenna type
- correct antenna height

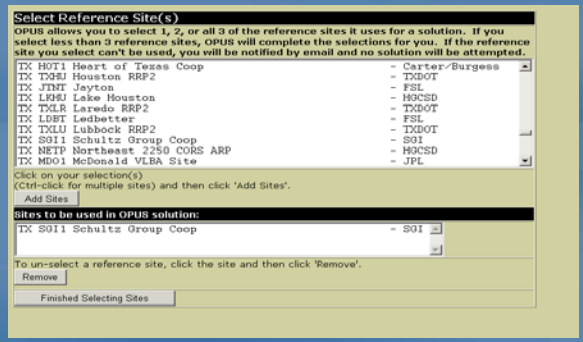
# Options

NATIONAL GEODETIC SURVEY

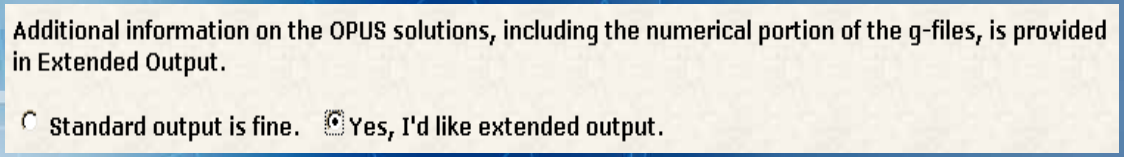



- Select state plane coordinate zone

- Select or exclude base stations including Cooperative CORS



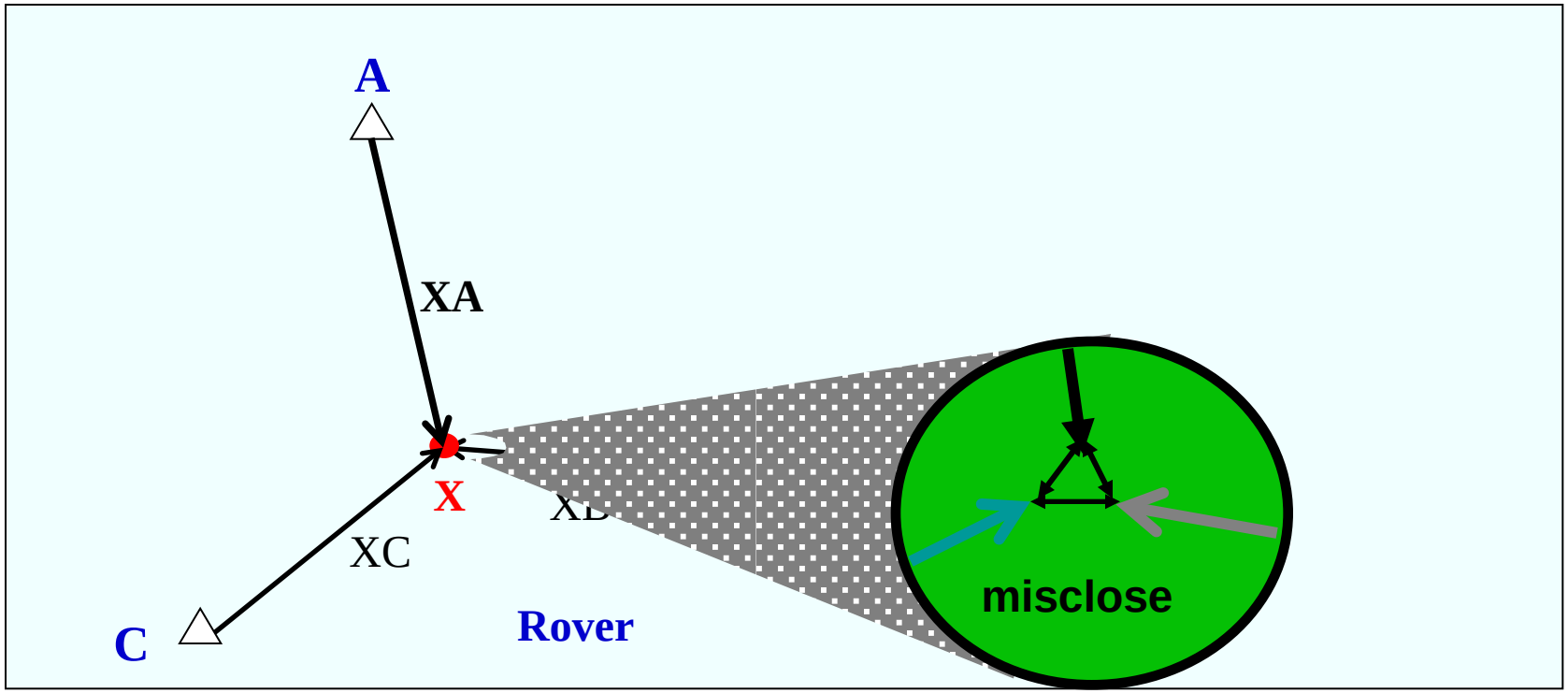

- Extended Output




- Set user profile

Associate antenna type, antenna height, SPC code, selected base stations and extended option choices with your email address

# How accuracies of OPUS coordinates are estimated




- Each OPUS solution uses 3 CORS
- As a result there are 3 independent baselines and 3 independent estimates of the coordinates
- The coordinates that OPUS gives are an average of the three values
- The errors are just the maximum difference between the three values

# OPUS Output
## *Standard*

```
FILE: corv0590.05o 000416827

 1008   NOTE:  Antenna offsets supplied by the user were zero.  Coordinates
 1008   returned will be for the antenna reference point (ARP).
 1008
                              NGS OPUS SOLUTION REPORT
                              ========================

      USER: jeff.olsen@noaa.gov                     DATE: January 13, 2006
RINEX FILE: corv059f.05o                            TIME: 19:08:14 UTC


  SOFTWARE: page5  0601.10 master3.pl             START: 2005/02/28  05:00:00
 EPHEMERIS: igs13121.eph [precise]                 STOP: 2005/02/28  06:59:30
  NAV FILE: brdc0590.05n                        OBS USED:  4228 /  4314   :  98%
  ANT NAME: ASH700936B_M    NONE            # FIXED AMB:    25 /    29   :  86%
ARP HEIGHT: 0.0                              OVERALL RMS: 0.013(m)
```

```
 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2005.1596)

         X:     -2498423.165(m)   0.018(m)          -2498423.872(m)   0.018(m)
         Y:     -3802822.048(m)   0.021(m)          -3802820.836(m)   0.021(m)
         Z:      4454737.695(m)   0.024(m)           4454737.792(m)   0.024(m)

       LAT:   44 35  7.91054      0.002(m)        44 35  7.92698      0.002(m)
     E LON:  236 41 43.48129      0.014(m)       236 41 43.42434      0.014(m)
     W LON:  123 18 16.51871      0.014(m)       123 18 16.57566      0.014(m)
    EL HGT:          107.485(m)   0.034(m)               107.108(m)   0.034(m)
 ORTHO HGT:          130.010(m)   0.043(m) [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 10)         SPC (3601 OR N)
Northing (Y) [meters]     4936954.907           105971.557
Easting (X)  [meters]      475821.322          2277335.385
Convergence  [degrees]    -0.21381402          -1.98897497
Point Scale                0.99960719           0.99994603
Combined Factor            0.99959034           0.99992918

US NATIONAL GRID DESIGNATOR: 10TDQ7582136955(NAD 83)
```

```
                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
AH2489 NEWP NEWPORT CORS ARP               N443506.072 W1240342.736   60138.7
AJ6959 CHZZ CAPE MEARS CORS ARP            N452911.437 W1235841.187  113322.4
DH4503 P376 EOLARESVR_OR2004 CORS ARP      N445628.313 W1230608.100   42648.2

                 NEAREST NGS PUBLISHED CONTROL POINT
AH2486      CORVALLIS CORS ARP             N443507.910 W1231816.519       0.0
```

# Reading OPUS Output

```
 USER: jeff.olsen@noaa.gov                    DATE: January 13, 2006
RINEX FILE: corv059f.05o                          TIME: 19:08:14 UTC

  SOFTWARE: page5  0601.10 master3.pl          START: 2005/02/28  05:00:00
 EPHEMERIS: igs13121.eph [precise]              STOP: 2005/02/28  06:59:30
  NAV FILE: brdc0590.05n                     OBS USED:  4228 /  4314   :  98%
  ANT NAME: ASH700936B_M    NONE           # FIXED AMB:    25 /    29   :  86%
ARP HEIGHT: 0.0                             OVERALL RMS: 0.013(m)
```

- Your email address & observation file. Solution run date & time
- The version of PAGES software used for processing
- The ephemeris used (OPUS will use the best available):
  "igs" final post-fit orbit--better than 1 cm (10-14 days wait)
  "igr" rapid post-fit orbit--better than 2 cm (17 hours wait)
  "igu" ultra-rapid predicted orbit--better than 20 cm (available immediately)
- Navigation file used
- The antenna type you selected and height of antenna reference point height you entered. Confirm that these are correct.

# Reading OPUS Output con't.

```
 USER: jeff.olsen@noaa.gov                    DATE: January 13, 2006
RINEX FILE: corv059f.05o                           TIME: 19:08:14 UTC

  SOFTWARE: page5  0601.10 master3.pl        START: 2005/02/28  05:00:00
 EPHEMERIS: igs13121.eph [precise]            STOP: 2005/02/28  06:59:30
  NAV FILE: brdc0590.05n                    OBS USED:  4228 /  4314   :  98%
  ANT NAME: ASH700936B_M    NONE          # FIXED AMB:    25 /    29   :  86%
ARP HEIGHT: 0.0                             OVERALL RMS: 0.013(m)
```

- Start & end dates & times of your file
- Ratio and % of observations used in solution
- Ratio and % of fixed/total ambiguities
- Overall RMS of the solution

# Guidelines for Good Solution

- Make sure antenna type and height are correct

- Review statistics:
  - at least 90% of observations should be used
  - OBS USED: 4228 / 4314 : 98%
  - at least 50% of the ambiguities should be fixed
  - # FIXED AMB: 25 / 29 : 86%
  - overall RMS should seldom exceed 0.030 m
  - OVERALL RMS: 0.013(m)

- In case of bad statistics, try choosing different CORS and re-submit.

# Reading OPUS Output con't.
## *Solution/Coordinates*

```
REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)
        X:      -2498423.165(m)   0.018(m)
        Y:      -3802822.048(m)   0.021(m)
        Z:       4454737.695(m)   0.024(m)
      LAT:    44 35  7.91054       0.002(m)
    E LON:   236 41 43.48129       0.014(m)
    W LON:   123 18 16.51871       0.014(m)
   EL HGT:           107.485(m)    0.034(m)
 ORTHO HGT:          130.010(m)    0.043(m)
```

```
ITRF00 (EPOCH:2005.1596)
-2498423.872(m)   0.018(m)
-3802820.836(m)   0.021(m)
 4454737.792(m)   0.024(m)
44 35  7.92698    0.002(m)
236 41 43.42434   0.014(m)
123 18 16.57566   0.014(m)
       107.108(m) 0.034(m)
[Geoid03 NAVD88]
```

- Reference frames. Epochs
- Position, xyz
- Peak-peak errors, xyz (range, max-min)
- Position, lat / long / eh / oh
- Peak-peak for lat/long etc
- Peak-peak errors may vary between NAD83 & ITRF
- Orthometric ht. is based on current geoid model

# OPUS Extended Output

# OPUS Extended Output: Base Station Information

```
BASE STATION INFORMATION
 STATION NAME: newp  a   10 (Newport; Newport, Oregon  USA)
  ANTENNA: ASH700936B_M                                    S/N=CR16197
 XYZ  -2548454.0306  -3769449.6516   4454636.5526  MON @ 1997.0000 (M)
 XYZ        -0.0067         0.0016        -0.0042  VEL (M/YR)
 NEU        -0.0000        -0.0000         1.4240  MON TO ARP (M)
 NEU        -0.0000         0.0000         0.1089  ARP TO L1 PHASE CENTER (M)
 NEU        -0.0000         0.0000         0.1274  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.0547         0.0131        -0.0343  VEL TIMES 8.1597 YRS
 XYZ        -0.5680        -0.8402         0.9996  MON TO ARP
 XYZ        -0.0434        -0.0643         0.0764  ARP TO L1 PHASE CENTER
 XYZ  -2548454.6967  -3769450.5430   4454637.5944  L1 PHS CEN @ 2005.1596
 XYZ         0.0000         0.0000         0.0000  + XYZ ADJUSTMENTS
 XYZ  -2548454.6967  -3769450.5430   4454637.5944  NEW L1 PHS CEN @ 2005.1596
 XYZ  -2548454.6533  -3769450.4787   4454637.5180  NEW ARP @ 2005.1596
 XYZ  -2548454.0852  -3769449.6385   4454636.5184  NEW MON @ 2005.1596
 LLH  44 35  6.08851  235 56 17.20688     21.9484  NEW L1 PHS CEN @ 2005.1596
 LLH  44 35  6.08851  235 56 17.20688     21.8395  NEW ARP @ 2005.1596
 LLH  44 35  6.08851  235 56 17.20688     20.4155  NEW MON @ 2005.1596
```

Base station and antenna used

Monument starting ITRF coordinates.

Velocity in XYZ.

NEU offsets

Position offsets at mid-pt of session

XYZ offsets and position

ITRF XYZ at mid-pt of session

ITRF lat long EH at mid-pt of session

These values are usually 0.000 for CORS (as they are here). The differences between initial and computed positions

These values are larger for the unknown station as we will see.

Time interval to multiply times velocity = decimal year at mid-pt of session minus 1997.0000 = 8.1597 yrs

Each CORS has a section like the one above, with ITRF xyz coordinates computed using HTDP velocities for the epoch of the observations (mid-point of the session). Note the above CORS has a <u>monument</u> separate from the ARP (positions coincide but ellipsoid heights are different).

-2548454.0852= 2548454.0306+-.0067*8.1597

-379449.6385= 379449.5516+ .0016*8.1597

445636.0852= 445636.5526+-.0042*8.1597

# OPUS Extended Output: Remote Station cont

```
XYZ  -2498422.0452  -3802821.8623   4454738.7108  L1 PHS CEN @ 2005.1596

BASELINE NAME:   newp  corv
XYZ        -1.8831         0.9528        -0.8303  + XYZ ADJUSTMENTS
XYZ  -2498423.9283  -3802820.9095   4454737.8805  NEW L1 PHS CEN @ 2005.1596
XYZ  -2498423.8860  -3802820.8451   4454737.8047  NEW ARP @ 2005.1596
XYZ  -2498423.8861  -3802820.8452   4454737.8047  NEW MON @ 2005.1596
LLH  44 35  7.92693  236 41 43.42403    107.2364  NEW L1 PHS CEN @ 2005.1596
LLH  44 35  7.92693  236 41 43.42403    107.1283  NEW ARP @ 2005.1596
LLH  44 35  7.92693  236 41 43.42403    107.1284  NEW MON @ 2005.1596
```

The first of 3 baselines being solved

- Preliminary ITRF coordinates for the remote station incorporating velocities computed for mid-point of session in the previous section

- Final positions based on this first vector. The XYZ adjustments are the difference between the initial and final positions.

- Final remote station ITRF latitude, longitude and ellipsoid height for this vector. Similar for the two remaining vectors.

# OPUS Extended Output: gfiles

```
                                    G-FILES

Axx2005 228   5 228
B2005 228 5 0   5 228 659 1 page5 v0411.19IGS     222 1 2 27NGS   2006 110IFDDFX
Iant_info.003        NGS   20060110
C00090001 -500301992   15  333712066   21   -1012864   25 X0595ACORVX0595ANEWP
D  1  2  8074967  1  3 -8657359  2  3 -8955936

Axx2005 228   5 228
B2005 228 5 0   5 228 659 1 page5 v0411.19IGS     222 1 2 27NGS   2006 110IFDDFX
Iant_info.003        NGS   20060110
C00090002  -49126271   27  884134550   32  707170134   51 X0595ACORVX0595ACHZZ
D  1  2  8158782  1  3 -8510487  2  3 -7117245

Axx2005 228   5 228
B2005 228 5 0   5 228 659 1 page5 v0411.19IGS     222 1 2 27NGS   2006 110IFDDFX
Iant_info.003        NGS   20060110
C00090003  286169924   13  144722673   17  281156013   20 X0595ACORVX0595AP376
D  1  2  9256643  1  3 -6469194  2  3 -7978592
```

Each of the three baselines has a section of A, B, I, C and D records. The specific record formats are listed in Bluebook Annex N, http://www.ngs.noaa.gov/FGCS/BlueBook/pdf/Annex_N.pdf. The C record contains dx, dy, dz vector components and related standard deviations. The D record contains correlations. The gfiles can be combined to do NGS-style adjustment with gfile and bfile (next slide).

# OPUS Extended Output: user-constructed

Extra lines inserted to show file structure

```
Axx2005 228   5 228
**first session, first vector:**
B2005 3 117 0   5 3 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090001 -500302065   15  333712070   20   -1012813   24 X0605ACORVX0605ANEWP
D  1  2  7430190  1  3 -8143037  2  3 -9277350
**first session, second vector:**
B2005 3 117 0   5 3 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090002  -49126038   18  884134654   28  707169927   35 X0605ACORVX0605ACHZZ
D  1  2  8612299  1  3 -8840443  2  3 -8385989
**first session, third vector:**
B2005 3 117 0   5 3 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090003  286169906   13  144722682   18  281156043   24 X0605ACORVX0605AP376
D  1  2  8779188  1  3 -7118769  2  3 -8693288
**second session, first vector:**
B2005 6 117 0   5 6 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090001 -500301975   13  333712099   17   -1012891   20 X1525ACORVX1525ANEWP
D  1  2  7783139  1  3 -8265107  2  3 -9194771
**second session, second vector:**
B2005 6 117 0   5 6 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090002  -49126063   14  884134679   20  707169869   26 X1525ACORVX1525ACHZZ
D  1  2  8654983  1  3 -8471449  2  3 -7513444
**second session, third vector:**
B2005 6 117 0   5 6 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090003  286169960   14  144722734   18  281155938   22 X1525ACORVX1525AP376
D  1  2  9047597  1  3 -7018973  2  3 -8300669
```

Example of two occupations of a station. Gfile constructed by deleting all but first “Axx2005…” lines from the extended output, then appending the two baselines’ gfiles to the first one, then adding second session results to the first session.

# Files for sample adjustment

Bfile from free adjustment:

```
000010*CO*HZTLOBS NGS   NATIONAL GEODETIC SURVEY                        20060112
000020*10*TEST OPUS SOLUTIONS TO CORVALLIS CORS
000030*12*200502200502JROJEFF OLSEN
000040*13*NORTH AMERICAN DATUM-83 GRS-80          63781370002982572221
      *80*0001NEWPORT CORS ARP              44350607244N124034273663W       ORAA
      *86*0001            N88                  20780A  A
      *80*0002CAPE MEARS CORS ARP           45291143836N123584118793W       ORAA
      *86*0002            N88                  51097A  A
      *80*0003EOLARESVR OR2004 CORS ARP     44562831336N123060810210W       ORAA
      *86*0003            N88                 181245A  A
      *80*0009CORV CORS ARP BY OPUS         44350791052N123181651975W       ORAA  (Pub = .91082, .51926)
      *86*0009            N88                 107516A  A                        (Pub = 107,514)
      *80*0005DDSN
      *86*0005
025640*AL*
```

(No orthom

Afile:

```
CC        0001                                44350607244N124034273663W  20780E
DD3
II 599999
MM3NYfrebbk
```

(Coordinates and EH for NEWP constrained)

Upper Part of composite Gfile. Four 2-hr sessions for CORV at different times of 2005 were sent to OPUS. Vectors for one of the four sessions shown.

```
Axx2005 228   5 228
B2005 3 117 0   5 3 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090001 -500302065   15  333712070   20   -1012813   24 X0605ACORVX0605ANEWP
D  1  2  7430190  1  3 -8143037  2  3 -9277350
B2005 3 117 0   5 3 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090002  -49126038   18  884134654   28  707169927   35 X0605ACORVX0605ACHZZ
D  1  2  8612299  1  3 -8840443  2  3 -8385989
B2005 3 117 0   5 3 11859 1 page5 v0601.10IGS     222 1 2 27NGS   2006 113IFDDFX
Iant_info.003        NGS   20060113
C00090003  286169906   13  144722682   18  281156043   24 X0605ACORVX0605AP376
D  1  2  8779188  1  3 -7118769  2  3 -8693288
```

# Getting There Faster –

# The RSGPS program and OPUS-RS

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

# OPUS: Online Positioning User Service

upload | view | about

*compute an accurate position for your GPS data file*

1. enter your email address

chris.pearson@noaa.gov

2. attach your DATA file

P:\Projects\00010041.06o Browse...

3. select your antenna type

TRM22020.00+GP Geodetic L1/L2 compact +groundplane

4. add your antenna height

2.0 meters

5a. customize your solution, report, and publishing options

OPTIONS

-or-

5b. choose a processor

Upload to RAPID-STATIC for L1/L2 GPS data > 15 min. < 2 hrs.

Upload to STATIC for L1/L2 GPS data > 2 hrs. < 48 hrs.

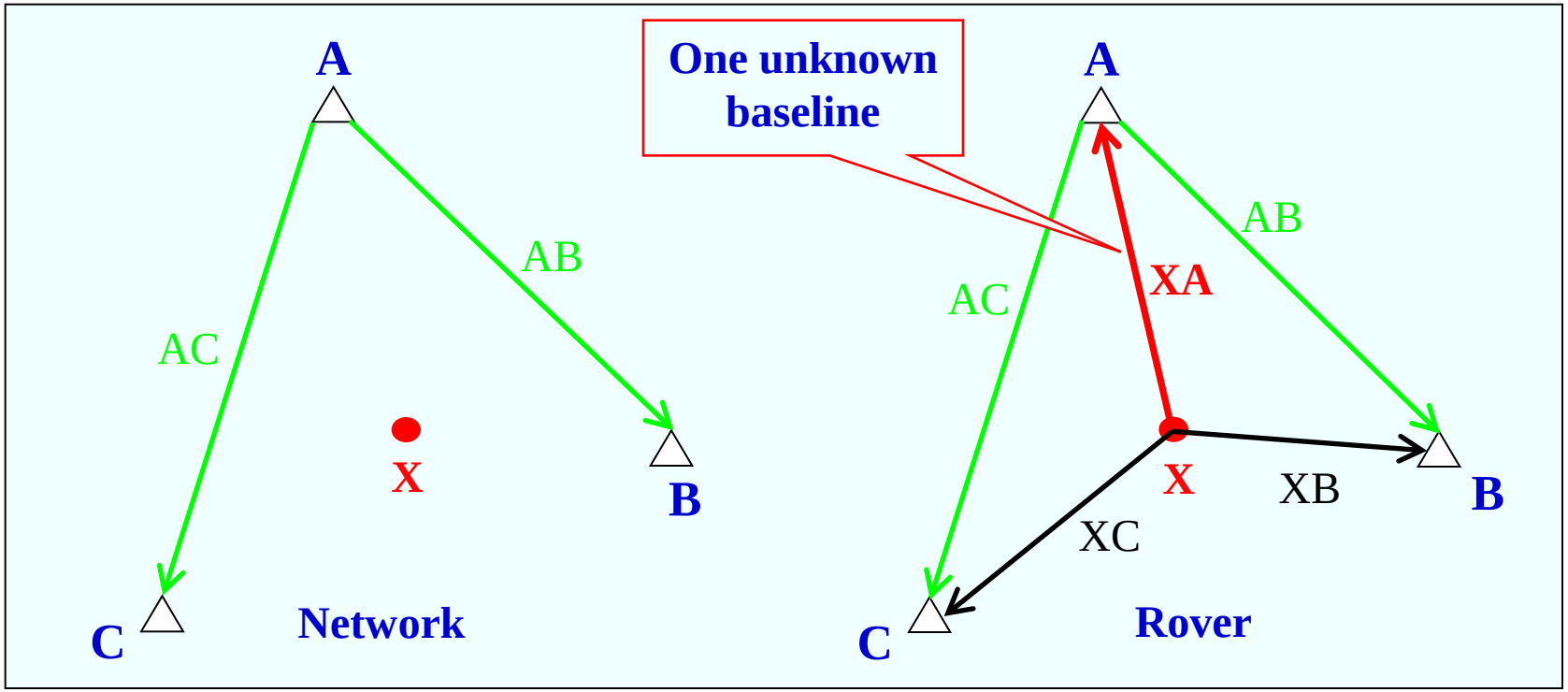
# RSGPS

- May be used in two modes :

  Network and Rover
- In network mode, only reference station observations are used to solve for ambiguities, tropo delay, and double difference ionospheric delays
- In rover mode, ionospheric delays and troposphere parameters are interpolated from reference stations to rover.

# Methodology – Rapid-Static Algorithm

## Rover solution schemes




$$\Delta ABX: \quad AB - XB + XA = 0 \quad \rightarrow \quad XB = XA + AB$$

$$\Delta ACX: \quad AC - XC + XA = 0 \quad \rightarrow \quad XC = XA + AC$$

**All three CORS stations contribute to the estimation of a single set of ambiguities**

$$\lambda_1 \phi_{1,ij}^{kl} - \rho_{ij}^{kl} - T_{ij}^{kl}\left(e_i, e_j\right) + I_{ij}^{kl} - \lambda_1 N_{1,ij}^{kl} = 0$$

$$\lambda_2 \phi_{2,ij}^{kl} - \rho_{ij}^{kl} - T_{ij}^{kl} + I_{ij}^{kl}\left(\frac{f_1^{\,2}}{f_2^{\,2}}\right) - \lambda_1 N_{2,ij}^{kl} = 0$$

$$P_{2,ij}^{kl} - \rho_{ij}^{kl} - T_{ij}^{kl} + I_{ij}^{kl}\left(\frac{f_1^{\,2}}{f_2^{\,2}}\right) = 0$$

$$P_{1,ij}^{kl} - \rho_{ij}^{kl} - T_{ij}^{kl} + I_{ij}^{kl} = 0$$

- The GPS observations are related to coordinates,
  - Tropospheric delays (which are a function of the elevation of the satellite and the T, P, and water vapor content of the atmosphere
  - and Ionospheric delays which are a function of the # of electrons in the ionosphere

# RSGPS vs conventional OPUS

- **Conventional OPUS determines tropospheric from individually for each measurement by comparing satellites at different elevations**
- **Ionospheric delays are determined from dual frequency measurements**
- **This means that must be several hours long for long baselines.**
- **OPUS RS determines the tropospheric and ionospheric delays from the network solution (where the coordinates are assumed to be known)**
  - **These are then estimated fpr the rover by interpolation**
- **This means that less time is required for a solution because the rover nolonger has to contain enough data to estimate the tropospheric and ionospheric delays**

# OPUSRS Output

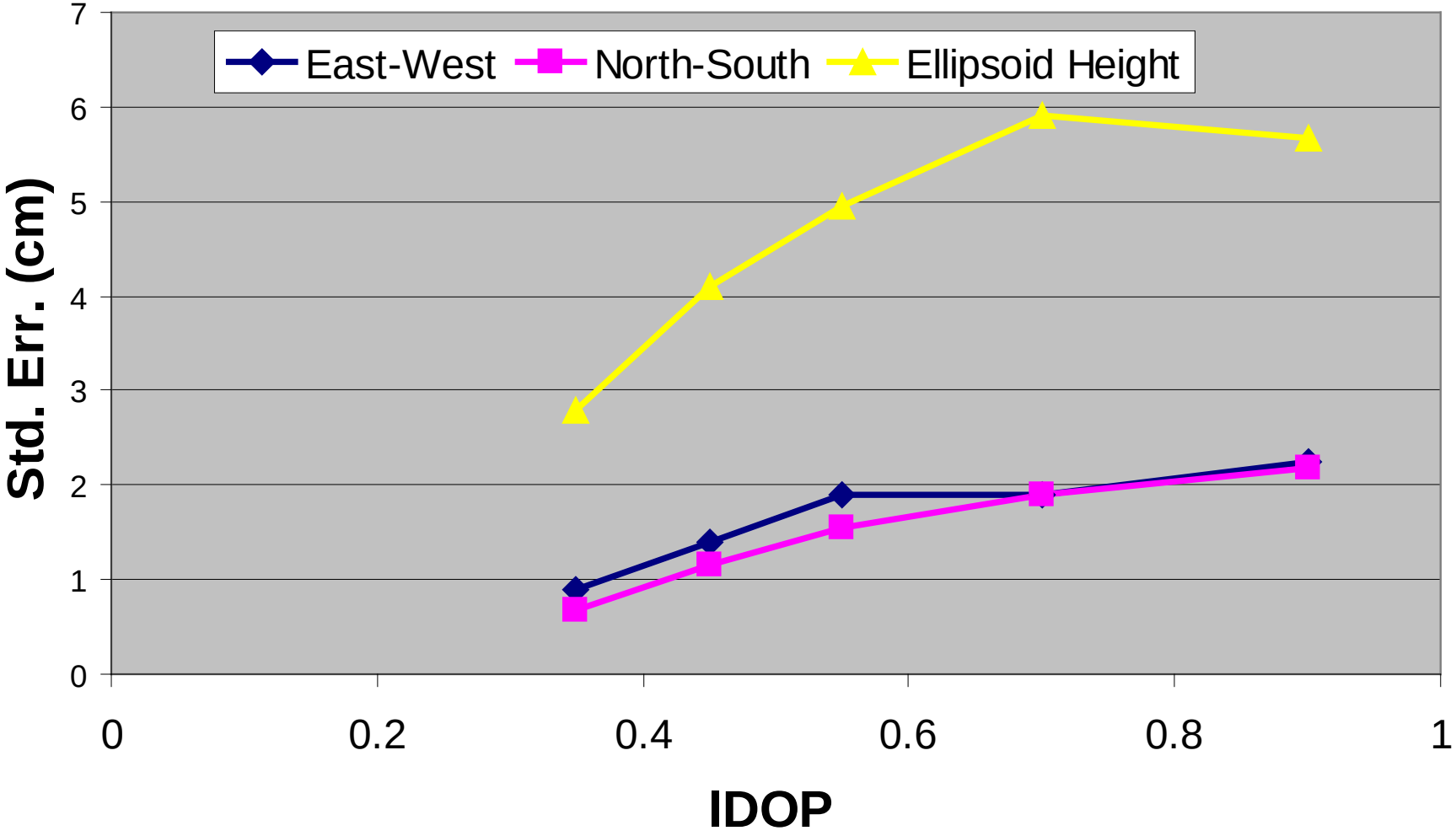
```
FILE: EFF01160.06o 000050229

                                NGS OPUS-RS SOLUTION REPORT
                                ===========================

      USER: Christopher.Pearson@illinois.gov DATE: August 21, 2007
RINEX FILE: eff0116p.06o                     TIME: 20:10:28 UTC


  SOFTWARE: rsgps  1.09 RS23.prl          START: 2006/04/26 15:23:50
 EPHEMERIS: igs13723.eph [precise]        STOP: 2006/04/26 17:35:40
  NAV FILE: brdc1160.06n                  OBS USED:  5780 /  7710   :  75%
  ANT NAME: LEIAX1202       NONE          QUALITY IND.  37.71/ 84.17
ARP HEIGHT: 2.0                           NORMALIZED RMS:        0.387
```

- The OPUS RS output is identical to conventional OPUS except that one extra statistical parameter is added
- This is the Quality indicator
- This is in place of the number of fixed ambiguities in the conventional OPUS output

# Quality indicator

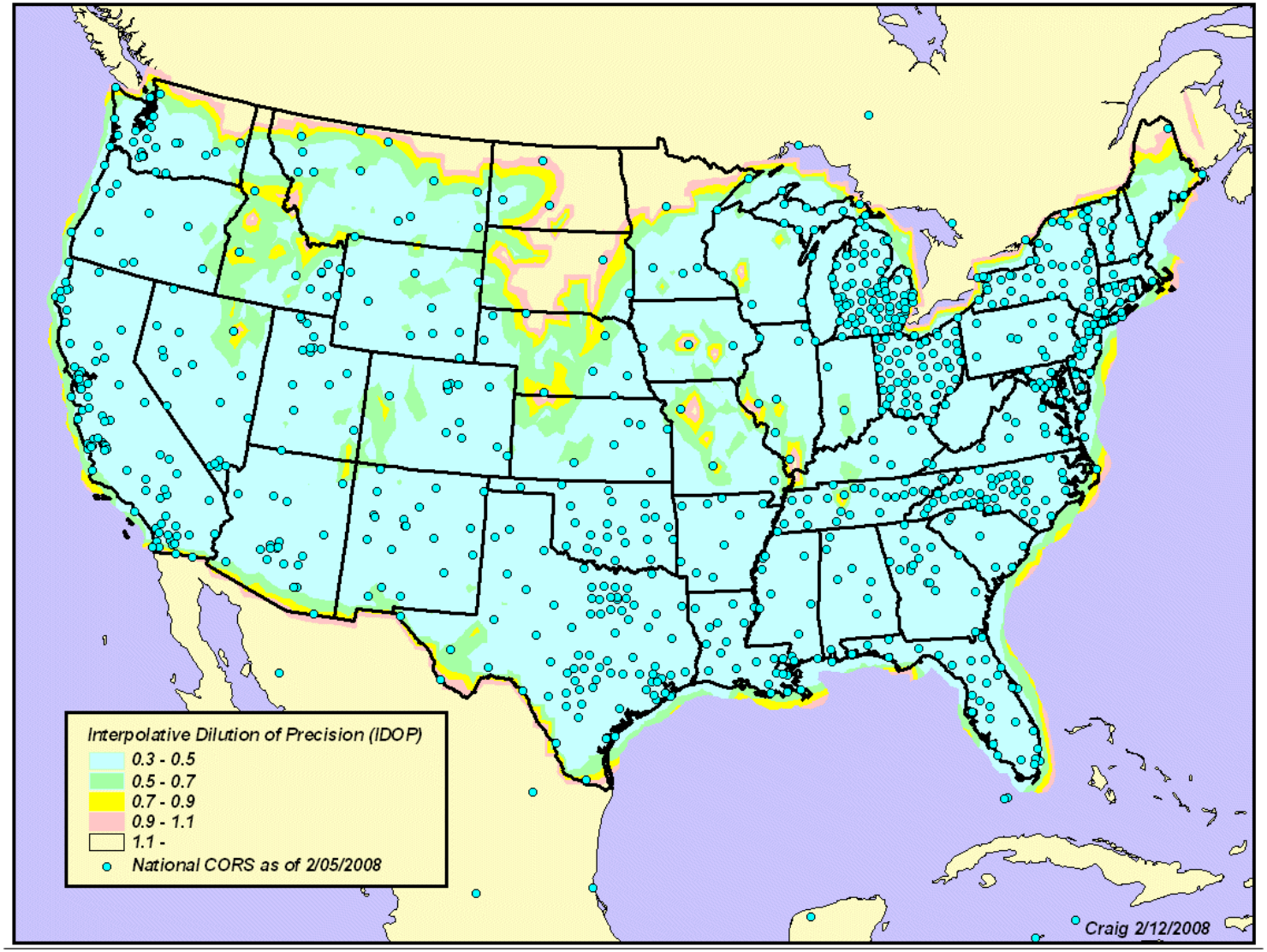
- OPUSRS calculates two sets of ambiguities the best candidate set and the second best candidate set. The Quality indicator is the ratio of the RMS values associated with these values
- The typical behavior is that the W-ratio grows with time, although it may drop slightly when a new satellite rises. The time required for the W-ratio to rise and stay above 3.0 is called the time-to-fix. The quality indicator reported by RSGPS is the average value of the W-ratio at the last three epochs.
- To be valid a solution should have a quality indicator greater than 1

# OPUS-RS Accuracy for 15-minute data sets

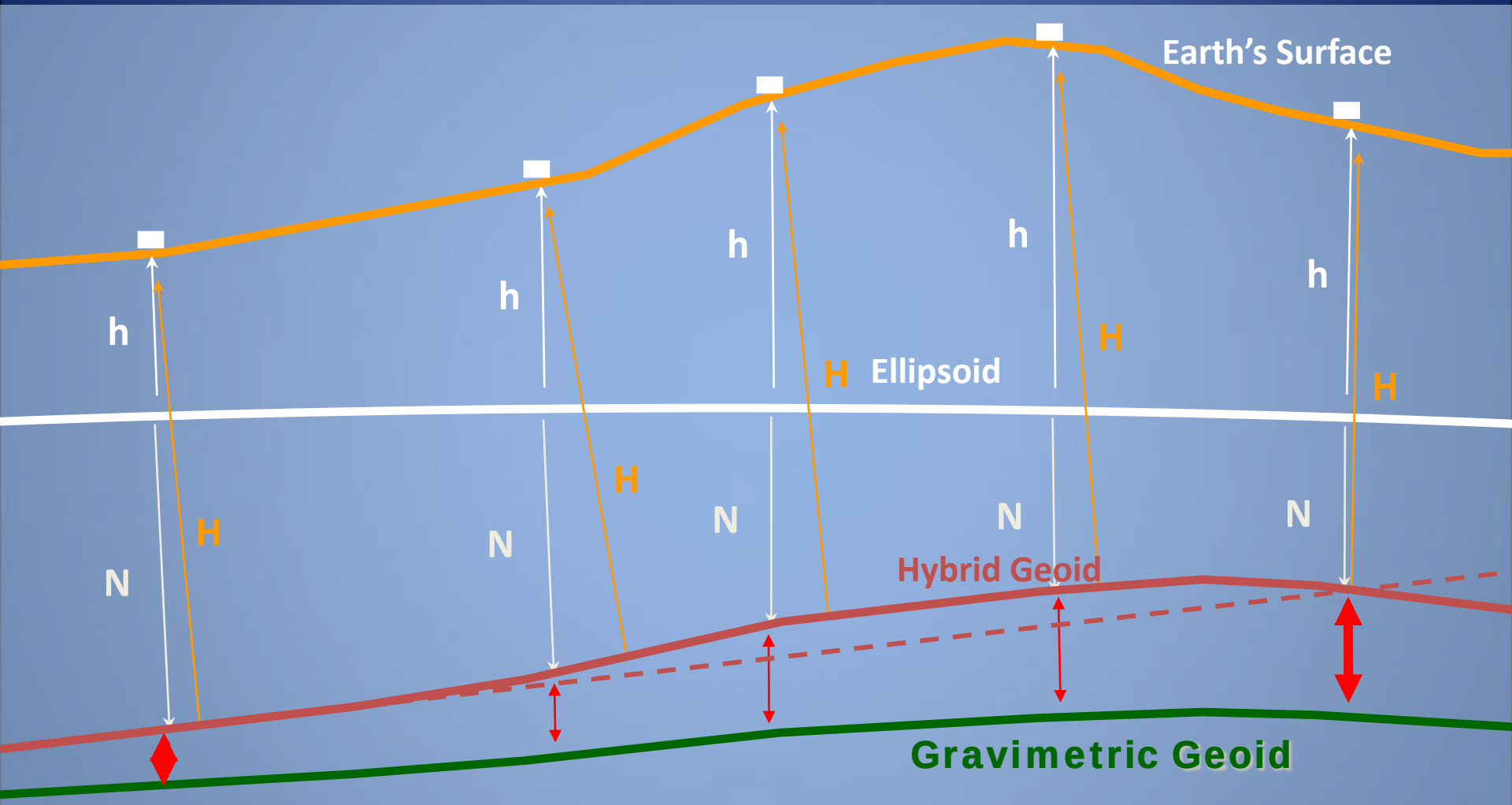


# OPUS-RS Coverage

## Interpolative Dilution of Precision (IDOP) Values

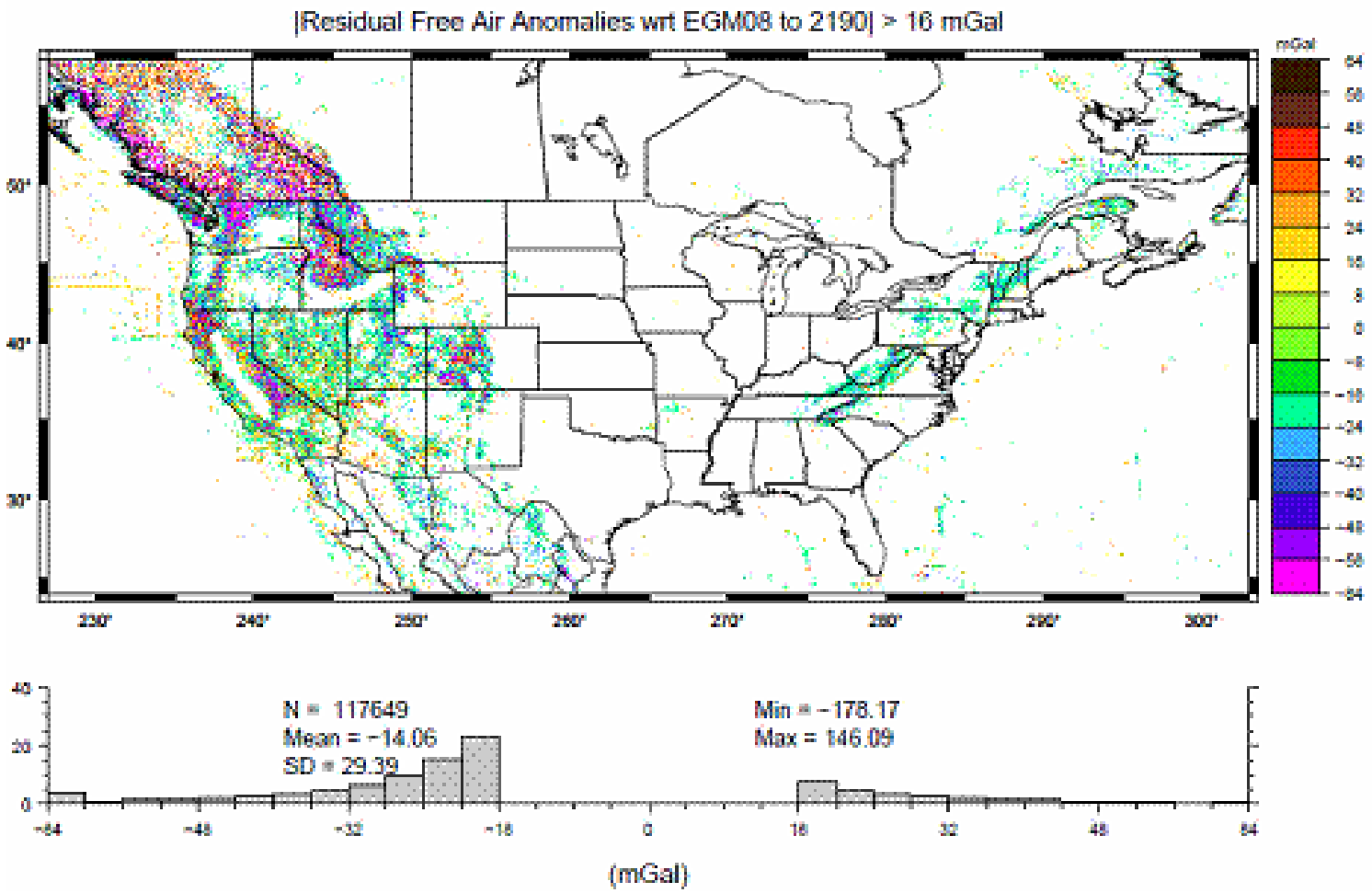


## Hybrid Geoid Height Models (e.g., GEOID09), Gravimetric Geoid Height Models (e.g., USGG2009) and Conversion Surfaces using GPS on BM data



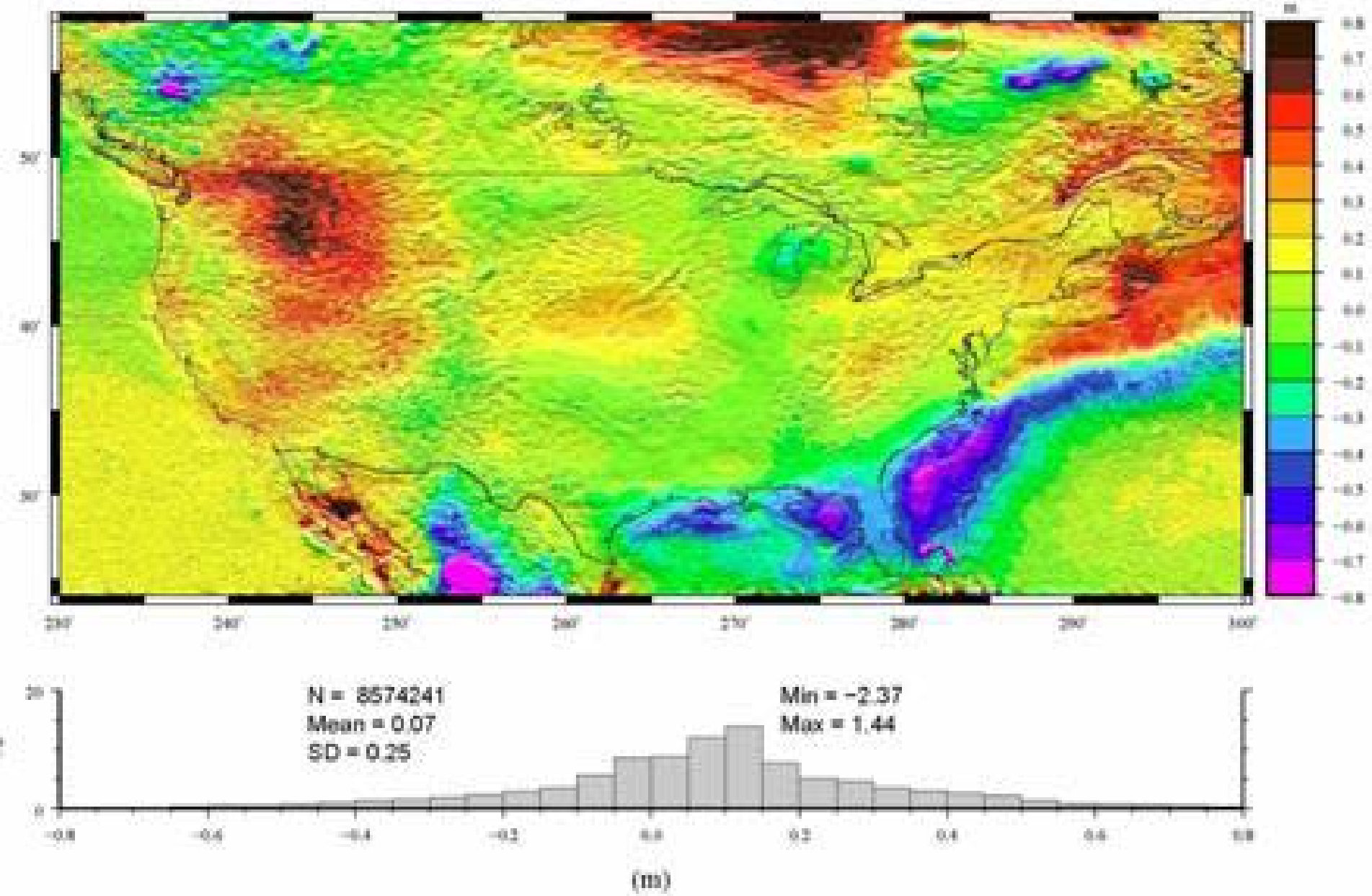

- Gravimetric Geoid systematic misfit to BM's but best fits "true" heights
- Hybrid Geoid "converted" to fit local BM's, so best fits NAVD 88 heights
- Conversion Surface model of systematic misfit derived from BM's in IDB

# Rejected Gravity Data

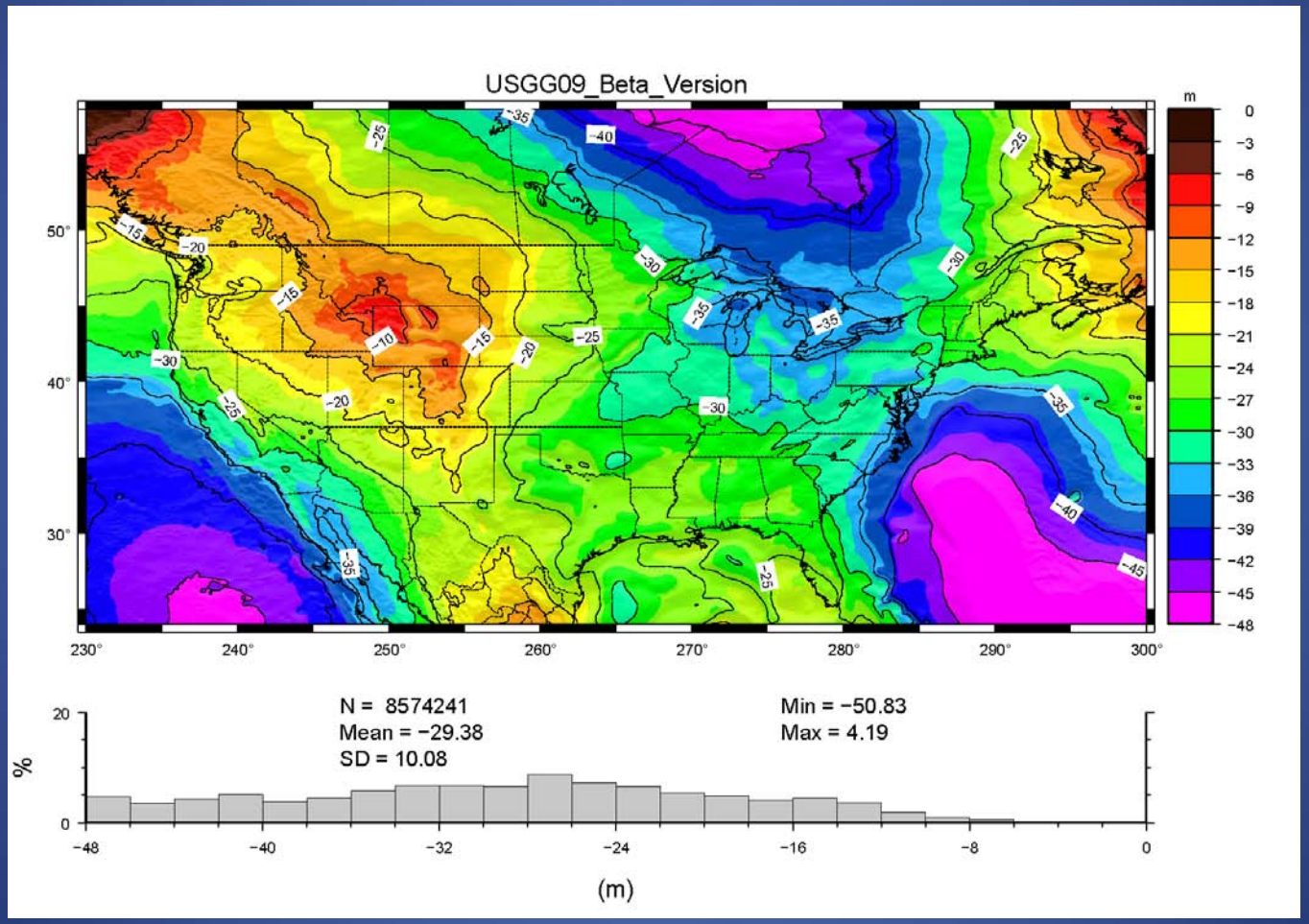



- Location of outliers of gravity datarejected from the USGG2009 model due to poor comparison with EGM08

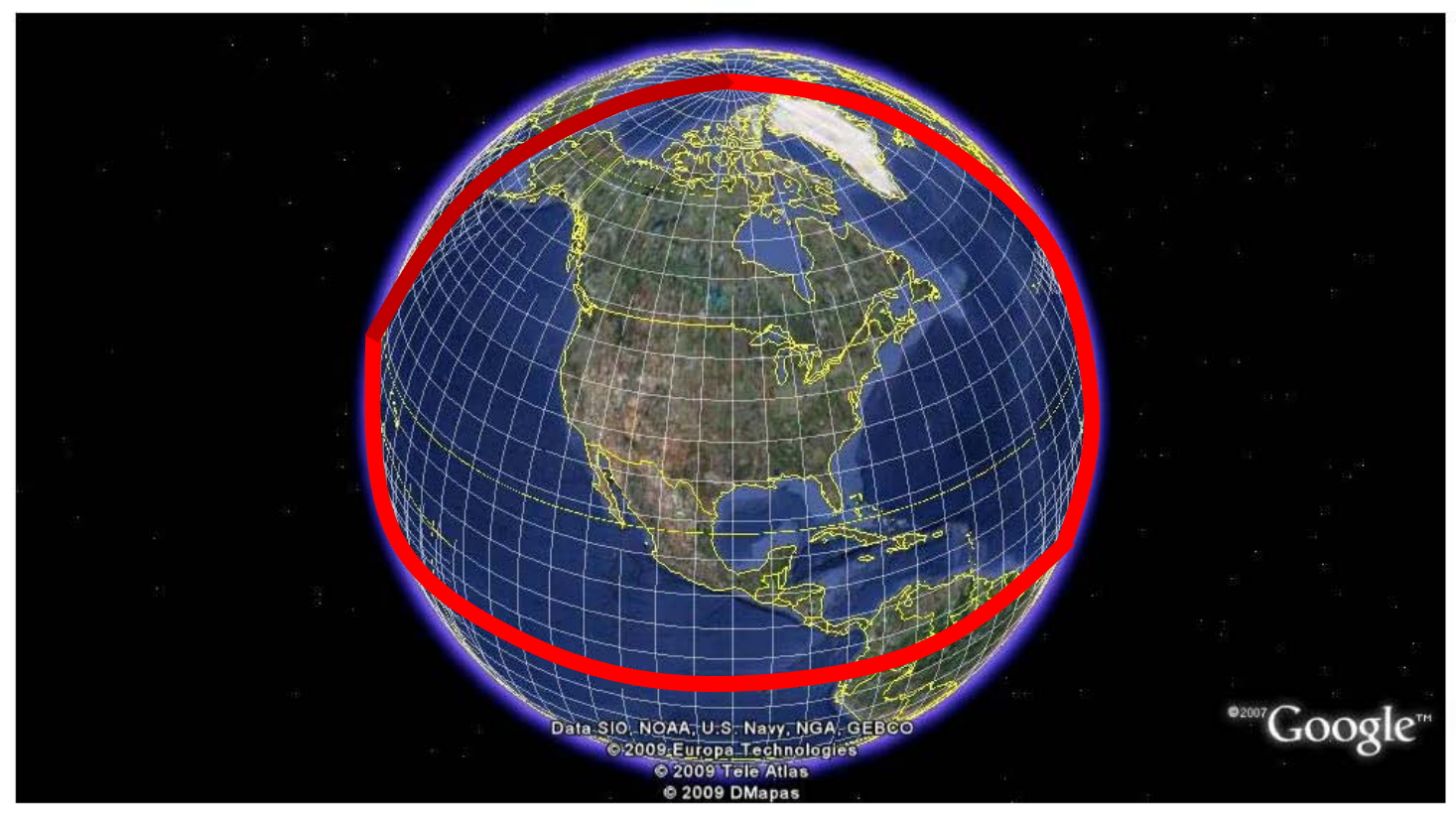
Geoid Differences: USGG08 – USGG03



# USGEOID2009 (Beta)



# A North American Geoid



# Question 8

- Will Grav D require a new vertical datum
  - Yes the GRAV D program essentially involves adopting a future highly improved gravimetric geoid (which will have an accuracy of about 1 cm) as the height datum.

# Question 9

- What is a hybrid geoid
  - It is a geoid that has been warped to fit local benchmark derived geoid heights. The gravity geoid represents the best measure of the “true” position of the geoid so warping it introduces distortions
- How will the GRAVD model be implemented in processing software and OPUS
  - GRAVD will just produce just another, more accurate geoid so there is no reason for it to be different from the current geoids in its implementation. We may no longer need to do a vertically constrained adjustment however.

# Question 1

- Detail the OPUS standard and long form reporting
  - The extended output contains much of the pages output along with the coordinates and QA/QC parameters summarized in the normal report
  - The most important extra parameter is the G file records because this allows users to include OPUS solutions in an adjustment

# Question 2

- What are the key factors to consider the in reviewing the long form output
  - Start with the QA/QC common with normal output
  - Check which CORS were used