SPE-178826-MS

# New Instrument Performance Models for Combined Wellbore Surveys Facilitate Optimal Use of Survey Information


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gyrodata



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# Jon Bang, PhD

- Development Engineer
- Experience
  - Gyrodata Since 2013
  - Petroleum Research Since 1991
- Speciality
  - Wellbore Positioning
  - Survey Quality
  - Position Uncertainty Analysis

gyrodata

- Founded in 1980, Houston, Texas
- Globally positioned to support a wide range of markets
  - Operating in **+80 countries**, with **+47 locations**
  - Customer base of **+625 Customers**
- Deliver precision wellbore placement & investigation solutions for drilling, completions, and production challenges
  - **Drilling Services:** Performance Motors, RSS, MWD, LWD
  - **Wellbore Surveying**: Gyro, GWD, Conventional Systems
  - **Production Logging**: MicroGuide, CBL, Caliper, Magnetic Thickness Detection

# CONTENTS

- Introduction / Challenge
- Solution
- Results
- Conclusions

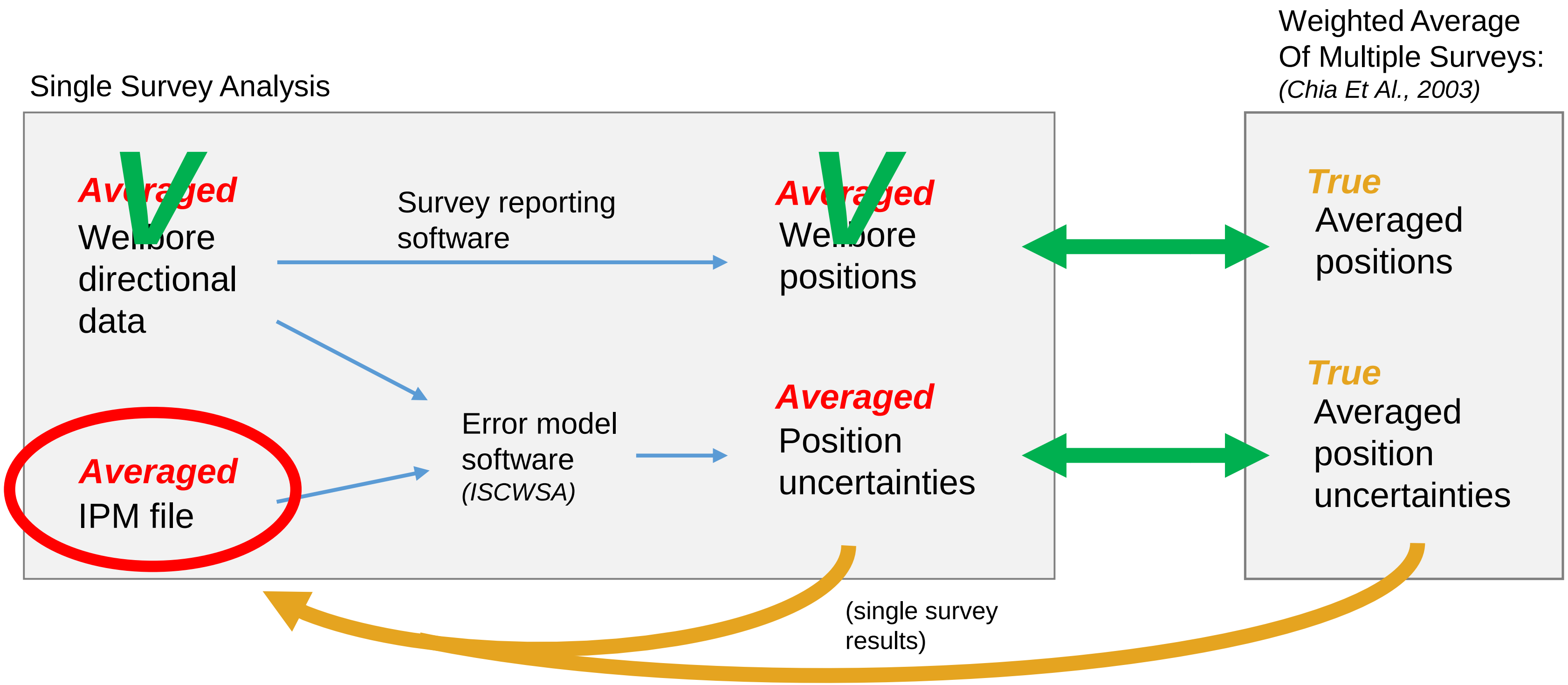
# BENEFITS OF MULTIPLE SURVEYS

- Mutual quality check and validation
- Weighted average gives optimal position estimate
- Weighted average gives minimum position uncertainty

# TWO ASSUMPTIONS

- The surveys must have passed standard quality tests
  - No gross errors
- The surveys must be interpolated to common MD

# ERROR ANALYSIS PROCEDURE



# IPM FILE EXAMPLE

IPM = «Instrument Performance Model» = Description of surveying tool's accuracy

MWD tool

```
#ShortName:MWD+IFR1+SAG
#Description:OWSG MWD + IFR1 + Sag Correction
# ....
# ....
# ....
#Name     Vector Tie-On  Unit    Value   Formula
drfr      e      r       m       0.35    1.0
drfr      s      r       m       2.2     1.0
drfs      s      s       m       1       1.0
dsfs      e      s       -       0.00056 tmd
dstg      e      g       im      2.5e-07 tmd*tvd
w_12      n      n       -       1       sin(inc)
w_34      n      n       -       1       sqrt(1-(w_12)^2)
xym1      i      s       d       0.1     w_12
xym2      l      s       d       0.1     w_12
xym3      i      s       d       0.1     cos(azi)*w_34
xym3      l      s       d       0.1     -sin(azi)*w_34
xym4      i      s       d       0.1     sin(azi)*w_34
xym4      l      s       d       0.1     cos(azi)*w_34
sag       i      s       d       0.08    (sin(inc))
decg      a      g       d       0.15    1.0
decr      a      r       d       0.1     1.0
dbhg      a      g       dnt     1500    1.0/(mtot*cos(dip))
dbhr      a      r       dnt     1500    1.0/(mtot*cos(dip))
amil      a      s       nt      300     sin(inc)*sin(azm)/(mtot*cos(dip))
abxy_t1   i      s       -       0.004   (-cos(inc))/gtot
abxy_t1   a      s       -       0.004   (tan(dip)*cos(inc)*sin(azm))/gtot
abxy_t2   l      s       -       0.004   (cos(inc)-tan(dip)*cos(azm)*sin(inc))/gtot
abz       i      s       -       0.004   (-sin(inc))/gtot
abz       a      s       -       0.004   (tan(dip)*sin(inc)*sin(azm))/gtot
asxy_t1   i      s       -       0.0005  (sin(inc)*cos(inc))/(2^0.5)
asxy_t1   a      s       -       0.0005  (-(tan(dip)*sin(inc)*cos(inc)*sin(azm)))/(2^0.5)
asxy_t2   i      s       -       0.0005  (sin(inc)*cos(inc))/2
asxy_t2   a      s       -       0.0005  (-(tan(dip)*sin(inc)*cos(inc)*sin(azm)))/2
asxy_t3   a      s       -       0.0005  (tan(dip)*sin(inc)*cos(azm)-cos(inc))/2
asz       i      s       -       0.0005  (-sin(inc)*cos(inc))
asz       a      s       -       0.0005  (tan(dip)*sin(inc)*cos(inc)*sin(azm))
mbxy_t1   a      s       nt      70      (-(cos(inc)*sin(azm)))/(mtot*cos(dip))
mbxy_t2   a      s       nt      70      (cos(azm))/(mtot*cos(dip))
mbz       a      s       nt      70      (-sin(inc)*sin(azm))/(mtot*cos(dip))
msxy_t1   a      s       -       0.0016  (sin(inc)*sin(azm)*(tan(dip)*cos(inc)+sin(inc)*cos(azm)))/(2^0.5)
msxy_t2   a      s       -       0.0016  (sin(azm)*(tan(dip)*sin(inc)*cos(inc)-(cos(inc))^2*cos(azm)-cos(azm)))/2
msxy_t3   a      s       -       0.0016  (cos(inc)*(cos(azm))^2-cos(inc)*(sin(azm))^2-tan(dip)*sin(inc)*cos(azm))/2
msz       a      s       -       0.0016  (-(sin(inc)*cos(azm)+tan(dip)*cos(inc))*sin(inc)*sin(azm))
```

- Fixed format table
- Contents vary according to surveying tool

Averaged IPM = Add another IPM model; add weighting factors to tune the output

# AVERAGED IPM FILE – REQUIREMENTS

- Results close to true average
  - Conservative
- Any combination of tools and range of uncertainties
- Any wellbore profile
- Any number of surveys
- Practical algorithm
  - Systematic approach
  - Easy implementation, automation

# STEP 1: IDENTICAL ERROR TERMS

- Correlated: Keep the one with smallest magnitude
- Uncorrelated: Keep one, with improved magnitude

# STEP 2: WEIGHTING FACTORS $w_1$, $w_2$

Error source groups in IPM:
D, I, A
(need individual weights)

Standard error analysis →

N, E, V uncertainties
(not suited as weights in DIA system)

Conversion to DIA-like system

Two independent meas.: $s_1$ ($\sigma_1^2$), $s_2$ ($\sigma_2^2$)

Weighted average: $s_{av} = w_1 s_1 + w_2 s_2$

LS weights: $w_1 = \frac{\sigma_2^2}{\sigma_1^2+\sigma_2^2}$ $w_2 = \frac{\sigma_1^2}{\sigma_1^2+\sigma_2^2}$

Averaged variance: $\sigma_{av}^2 = \frac{\sigma_1^2 \sigma_2^2}{\sigma_1^2+\sigma_2^2}$

N measurements:

$$s_{av(N)} = \sum_{i=1}^{N} w_i s_i$$

$$w_i = \frac{1/\sigma_i^2}{\sum_{i=1}^{N}(1/\sigma_i^2)}$$

$$\sigma_{av(N)}^2 = \frac{1}{\sum_{i=1}^{N}(\sigma_i^2)}$$

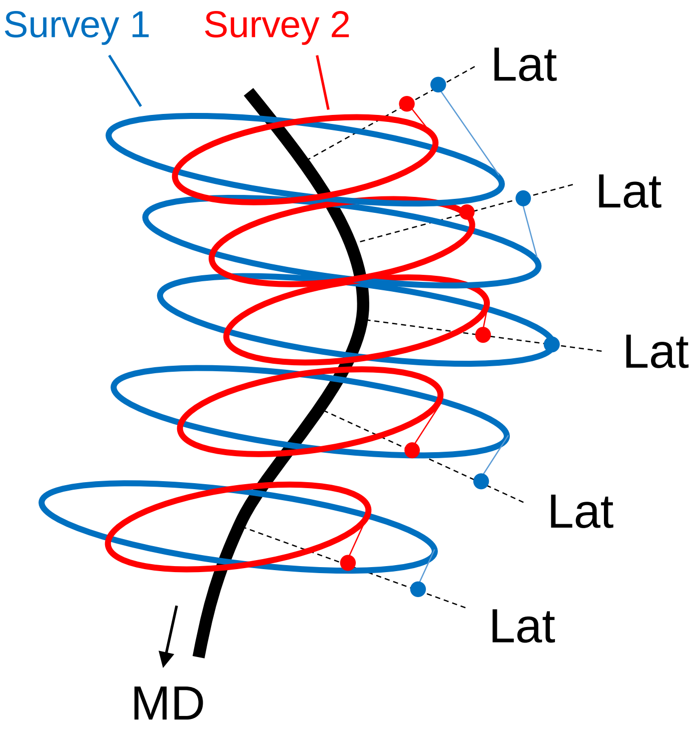
AH, HS, Lat uncertainties used in $w_1, w_2$:

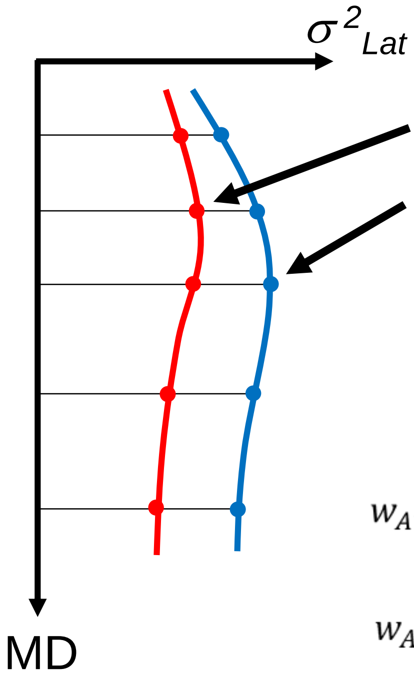
$$w_{D1} = \frac{\sigma_{AH2}^2}{\sigma_{AH1}^2+\sigma_{AH2}^2} \qquad w_{D2} = \frac{\sigma_{AH1}^2}{\sigma_{AH1}^2+\sigma_{AH2}^2}$$

$$w_{I1} = \frac{\sigma_{HS2}^2}{\sigma_{HS1}^2+\sigma_{HS2}^2} \qquad w_{I2} = \frac{\sigma_{HS1}^2}{\sigma_{HS1}^2+\sigma_{HS2}^2}$$

$$w_{A1} = \frac{\sigma_{Lat2}^2}{\sigma_{Lat1}^2+\sigma_{Lat2}^2} \qquad w_{A2} = \frac{\sigma_{Lat1}^2}{\sigma_{Lat1}^2+\sigma_{Lat2}^2}$$

# AH-HS-Lat SYSTEM IS LOCAL => WEIGHTS ARE APPROXIMATE



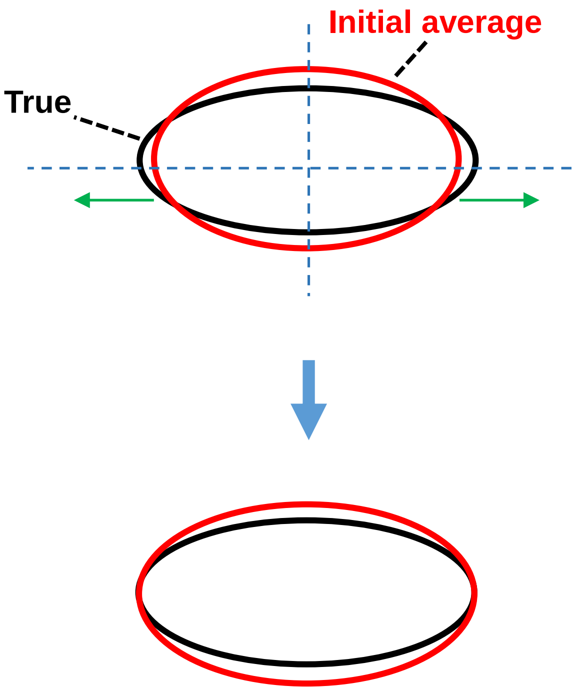




Largest values are used for weighting factors

$$w_{A1} = \frac{max(\sigma^2_{Lat2})}{max(\sigma^2_{Lat1}) + max(\sigma^2_{Lat2})}$$

$$w_{A2} = \ldots\ldots$$

# STEP 3: ADJUSTMENT FACTORS $B_D$, $B_I$, $B_A$




## Problem

- True average may be under-estimated

## Solution

- Ellipsoid orientations are approximately equal
- $B_D$, $B_I$, $B_A$ = ratio of ellipsoid axes
- Magnify $w_{A1}$ and $w_{A2}$ by $B_A$, etc.
- Update => final averaged IPM file

# AVERAGED IPM FILE, CASE 1

Depth
Misalign.
Sag

**STEP 1**

Identical terms are combined

```
#ShortName: Averaged IPM file
#  Survey 1 (top), IPM file:        MWD+IFR1+SAG.ipm
#  Survey 1, Wellpath file:         mwd-survey.txt
#  Survey 2 (bottom), IPM file:     GYRO-CONT-SPE178826.ipm
#  Survey 2, Wellpath file:         gyro-continuous-survey.txt
#Name       Vect  Tie-On  Unit    Value   Formula
drfr        e     r       m       0.247   1.04*((1.0))
drfr        s     r       m       1.56    1.04*((1.0))
drfs        s     s       m       0.707   1.04*((1.0))
dsfs        e     s       -       0.00040 1.04*((tmd))
dstg        e     g       im      1.77e-7 1.04*((tmd*tvd))
w_12        n     n       -       1       ((sin(inc)))
w_34        n     n       -       1       ((sqrt(1-(w_12)^2)))
xym1        i     s       d       0.0447  1.12*((w_12))
xym2        l     s       d       0.0447  1.12*((w_12))
xym3        i     s       d       0.0447  1.12*((cos(azi)*w_34))
xym3        l     s       d       0.0447  1.12*((-sin(azi)*w_34))
xym4        i     s       d       0.0447  1.12*((sin(azi)*w_34))
xym4        l     s       d       0.0447  1.12*((cos(azi)*w_34))
sag         i     s       d       0.0566  1.12*(((sin(inc))))
decg        a     g       d       0.15    1.12*0.620*(1.0))
decr        a     r       d       0.1     1.12*0.620*(1.0))
dbhg        a     g       dnt     1500    1.12*0.620*(1.0/(mtot*cos(dip))))
dbhr        a     r       dnt     1500    1.12*0.620*(1.0/(mtot*cos(dip))))
amil        a     s       nt      300     1.12*0.620*(sin(inc)*sin(azm)/(mtot*cos(dip))))
abxy_ti1    i     s       -       0.004   1.12*0.305*((-cos(inc))/gtot))
abxy_ti1    a     s       -       0.004   1.12*0.620*((tan(dip)*cos(inc)*sin(azm))/gtot))
abxy_ti2    l     s       -       0.004   1.12*0.620*((cos(inc)-tan(dip)*cos(azm)*sin(inc))/gtot))
abz         i     s       -       0.004   1.12*0.305*((-sin(inc))/gtot))
abz         a     s       -       0.004   1.12*0.620*((tan(dip)*sin(inc)*sin(azm))/gtot))
asxy_ti1    i     s       -       0.0005  1.12*0.305*((sin(inc)*cos(inc))/(2^0.5)))
asxy_ti1    a     s       -       0.0005  1.12*0.620*((-(tan(dip)*sin(inc)*cos(inc)*sin(azm)))/(2^0.5)))
asxy_ti2    i     s       -       0.0005  1.12*0.305*((sin(inc)*cos(inc))/2))
asxy_ti2    a     s       -       0.0005  1.12*0.620*((-(tan(dip)*sin(inc)*cos(inc)*sin(azm)))/2))
asxy_ti3    a     s       -       0.0005  1.12*0.620*((tan(dip)*sin(inc)*cos(azm)-cos(inc))/2))
asz         i     s       -       0.0005  1.12*0.305*((-sin(inc)*cos(inc))))
asz         a     s       -       0.0005  1.12*0.620*((tan(dip)*sin(inc)*cos(inc)*sin(azm))))
mbxy_ti1    a     s       nt      70      1.12*0.620*((-(cos(inc)*sin(azm)))/(mtot*cos(dip))))
mbxy_ti2    a     s       nt      70      1.12*0.620*((cos(azm))/(mtot*cos(dip))))
mbz         a     s       nt      70      1.12*0.620*((-sin(inc)*sin(azm))/(mtot*cos(dip))))
msxy_ti1    a     s       -       0.0016  1.12*0.620*((sin(inc)*sin(azm)*(tan(dip)*cos(inc)+sin(inc)*cos(azm)))/(2^0.5)))
msxy_ti2    a     s       -       0.0016  1.12*0.620*((sin(azm)*(tan(dip)*sin(inc)*cos(inc)-(cos(inc))^2*cos(azm)-cos(azm)))/2))
msxy_ti3    a     s       -       0.0016  1.12*0.620*((cos(inc)*(cos(azm))^2-cos(inc)*(sin(azm))^2-tan(dip)*sin(inc)*cos(azm))/2))
msz         a     s       -       0.0016  1.12*0.620*((-(sin(inc)*cos(azm)+tan(dip)*cos(inc))*sin(inc)*sin(azm))))
axyz_mis    i     s       d       0.0095  1.12*0.695*(1))
axyz_sf     i     s       -       0.00011 1.12*0.695*(1.3*sin(inc)*cos(inc)))
axyz_zb     i     s       -       0.0017  1.12*0.695*(sin(inc)/gtot))
axyx_xyb    i     r       -       0.0012  1.12*0.695*(cos(inc)/gtot))
ngxy_b1     n     n       -       1       ((sin(azt)/(erot*cos(inc))))     0     15
ngxy_b2     n     n       -       1       ((cos(azt)/erot))     0     15
ngxy_gd1    n     n       -       1       ((cos(azt)*sin(inc)/erot))     0     15
ngxy_gd4    n     n       -       1       ((sin(azt)*sin(inc)/cos(inc)/erot))     0     15
ngxy_rn     n     n       -       1       ((sqrt(1-(cos(azt)^2)*(sin(inc)^2))/(erot*cos(inc))))     0     15
gxy_b1      a     s       d       0.05    1.12*0.380*(ngxy_b1))
gxy_b2      a     s       d       0.05    1.12*0.380*(ngxy_b2))
gxy_gd1     a     s       d       0.2     1.12*0.380*(ngxy_gd1))
gxy_gd4     a     s       d       0.3     1.12*0.380*(ngxy_gd4))
gxy_rn      a     r       d       0.2     1.12*0.380*(ngxy_rn))     0     15
gxy_rn      a     s       d       0.2     1.12*0.380*(0.4082*ngxy_rn))     15     150
runsp       n     n       m       2800    ((1))
ngxy_ld     n     n       -       1       ((ngxy_ld+smd/sin(inc-0.5*din)))     15     150
ngxy_rwd    n     n       -       1       ((ngxy_rwd+smd/((sin(inc-0.5*din))^2)))  15     150
gxy_ld      a     s       d       0.12    1.12*0.380*(ngxy_ld/runsp))
gxy_rwd     a     s       d       0.25    1.12*0.380*(sqrt(ngxy_rwd/runsp)))
```

**MWD**

**Cont. gyro**

**STEP 2**

Weighting factors

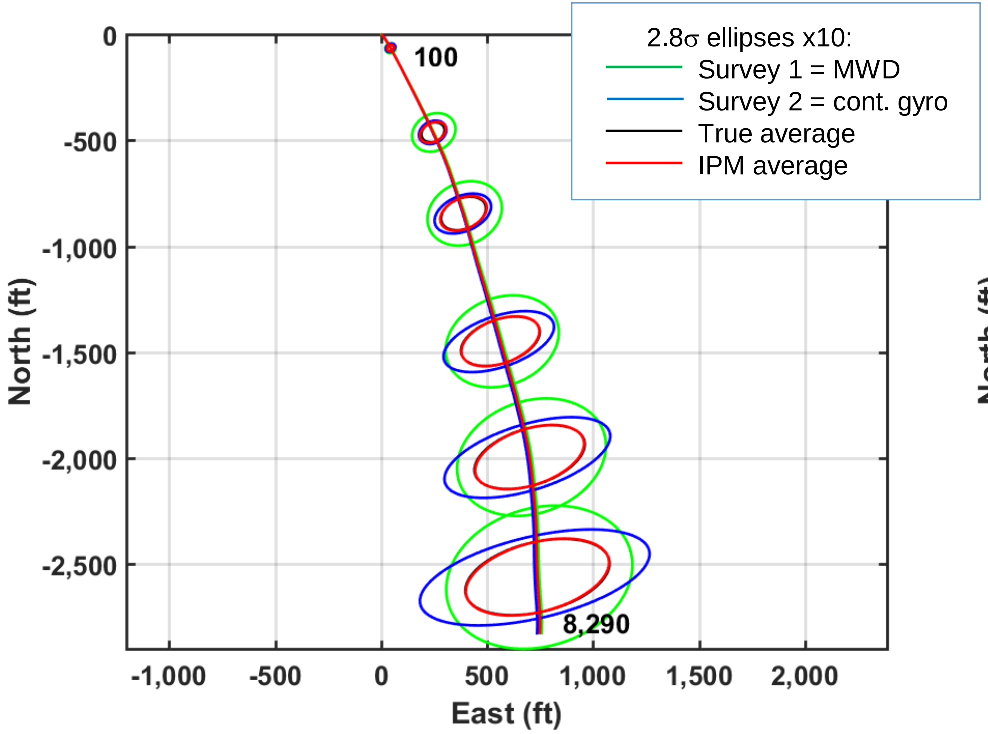
$W_{I,MWD}$ $W_{I,gyro}$
$W_{A,MWD}$ $W_{A,gyro}$

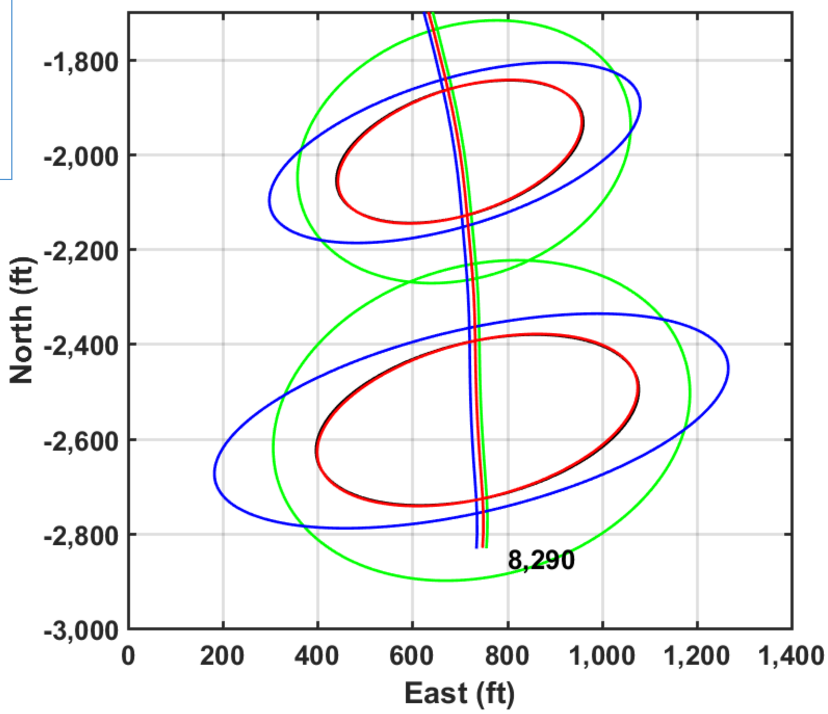
**STEP 3**

Adjustment factors

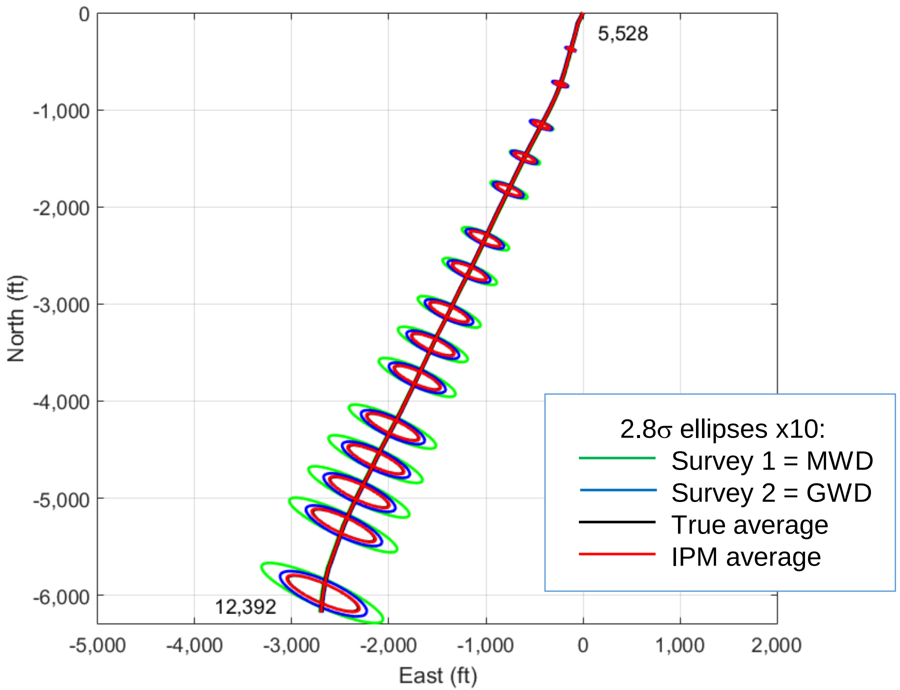
$B_D$ $B_I$ $B_A$

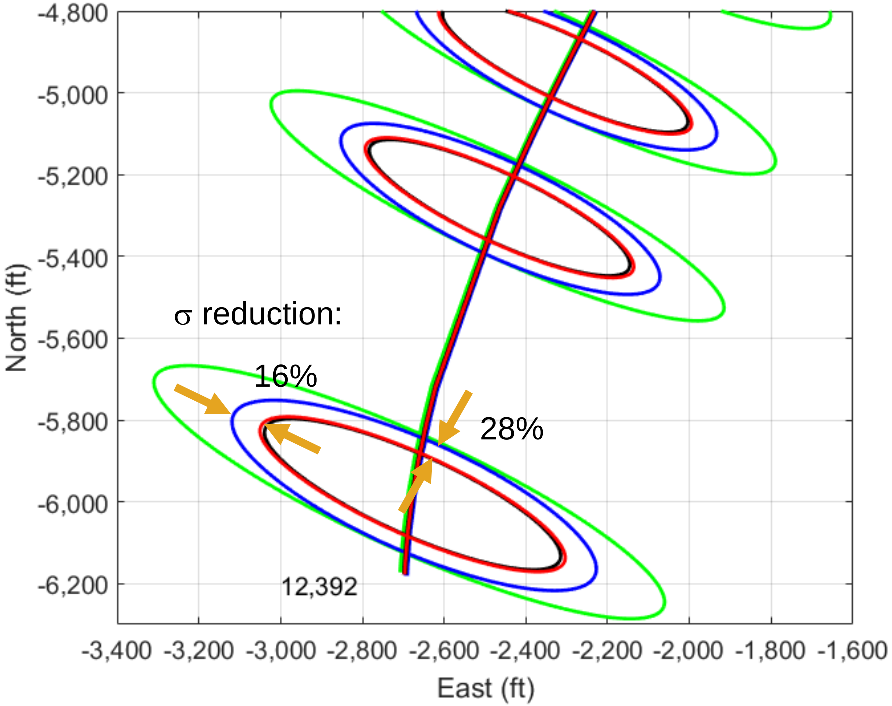
# CASE 1: Inc = 0-30º, N-S



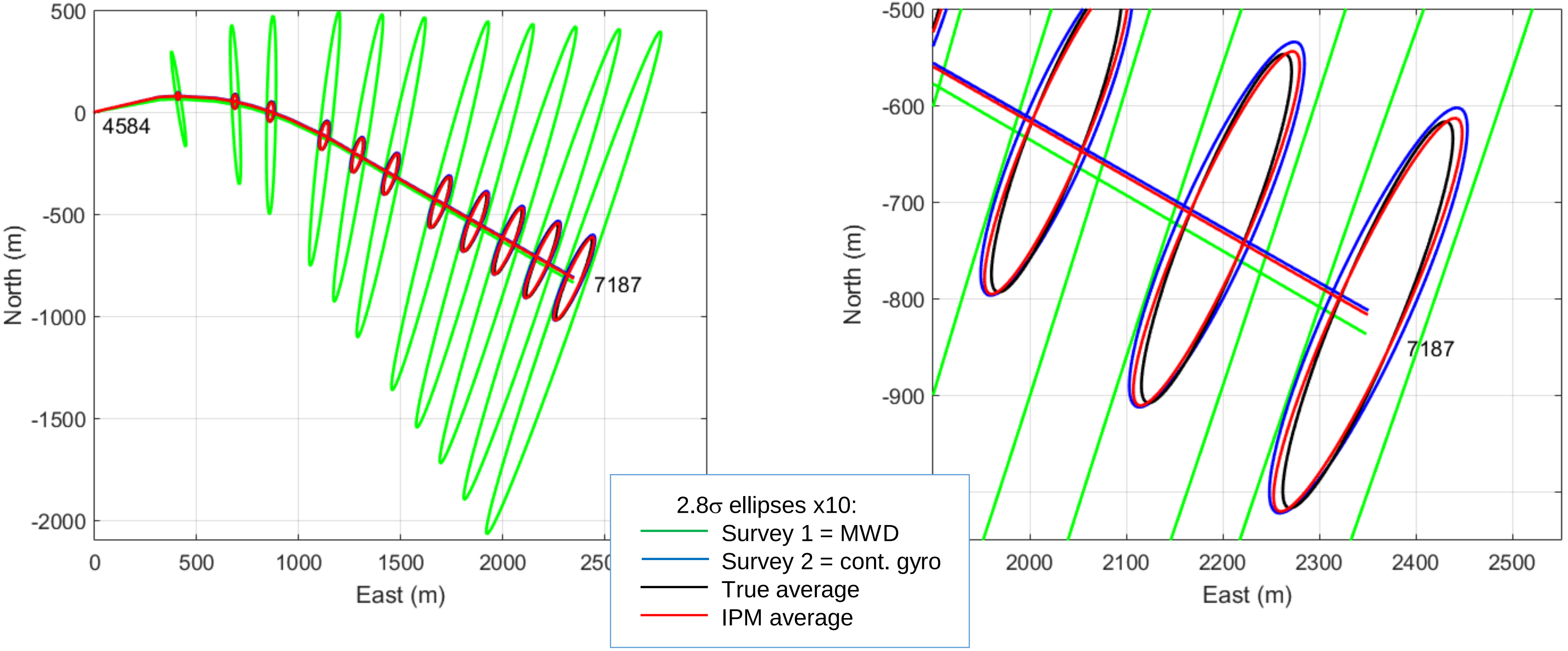



# CASE 2: NEAR HORIZONTAL, N-S



# CASE 3: NEAR HORIZONTAL, E-W



# CONCLUSIONS: AVERAGING METHOD

- Individual surveys must pass QC routines: no gross errors
- Algorithm
  - D, I, A weighting factors + adjustment factors
  - Analytic, no iteration, suited for automation
- Results
  - Close to true average, conservative
  - Any tools, any uncertainties
  - Any wellbore profile; best accuracy in tangential sections
  - Any number of surveys
- Possible challenges
  - Validation of method for different well profiles

# CONCLUSIONS: BENEFITS OF AVERAGING

- One survey data set per wellbore
- Optimal wellbore positions + improved accuracy
- Optimise survey programs
- Improved reliability of anti-collision calculations
- May turn unfeasible projects into achievable ones
    - Small drilling targets
    - Long extended reach wells
    - Highly congested fields

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# Thank you