

# **Raw Data**

*to Improve*

- **Accuracy**
- **Integrity**
- **Availability**

**of Satellite Navigation**



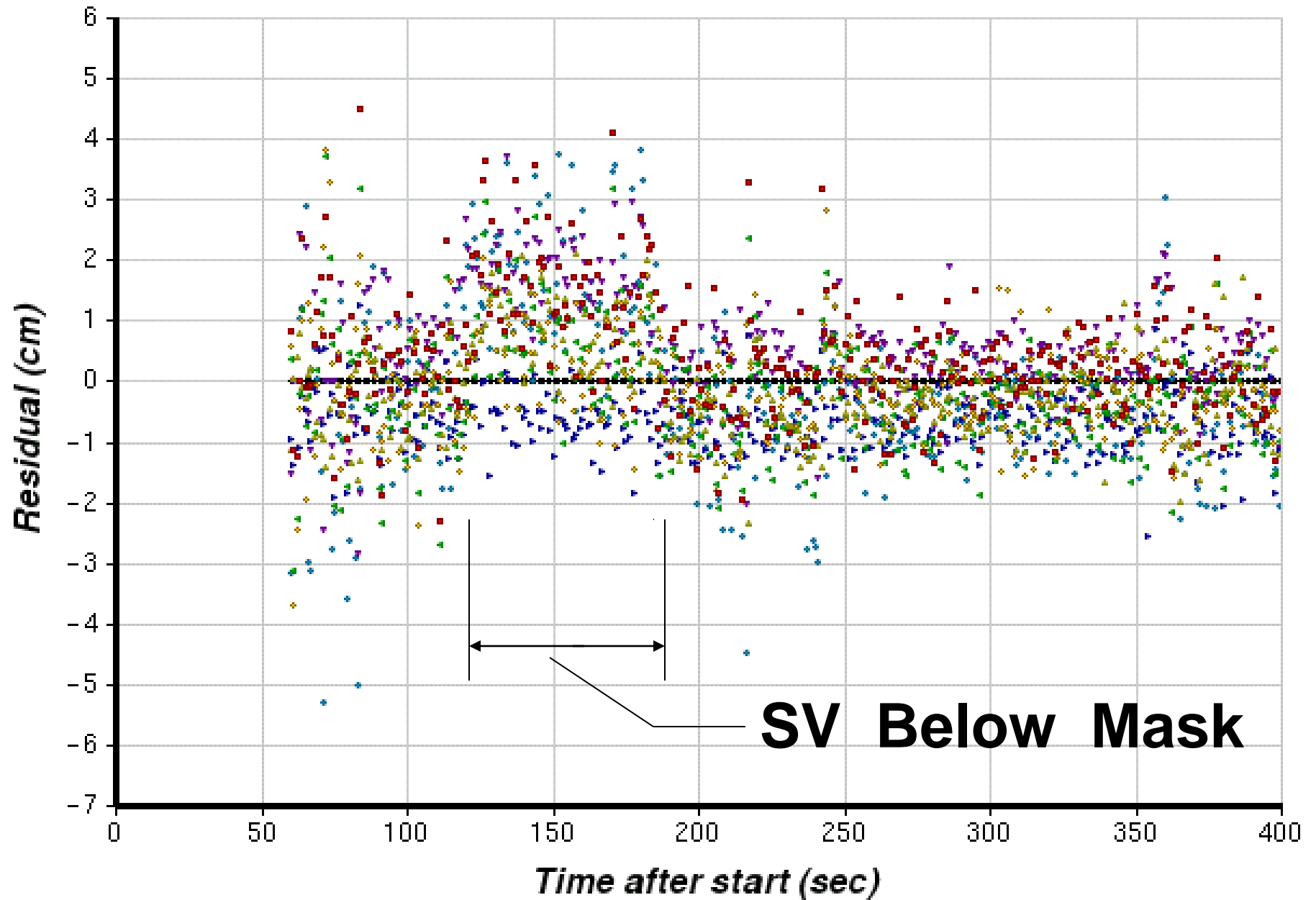
National Space-Based Positioning,  
Navigation, Timing Advisory Board

June 11-12, 2015      Annapolis MD

*James L. Farrell*

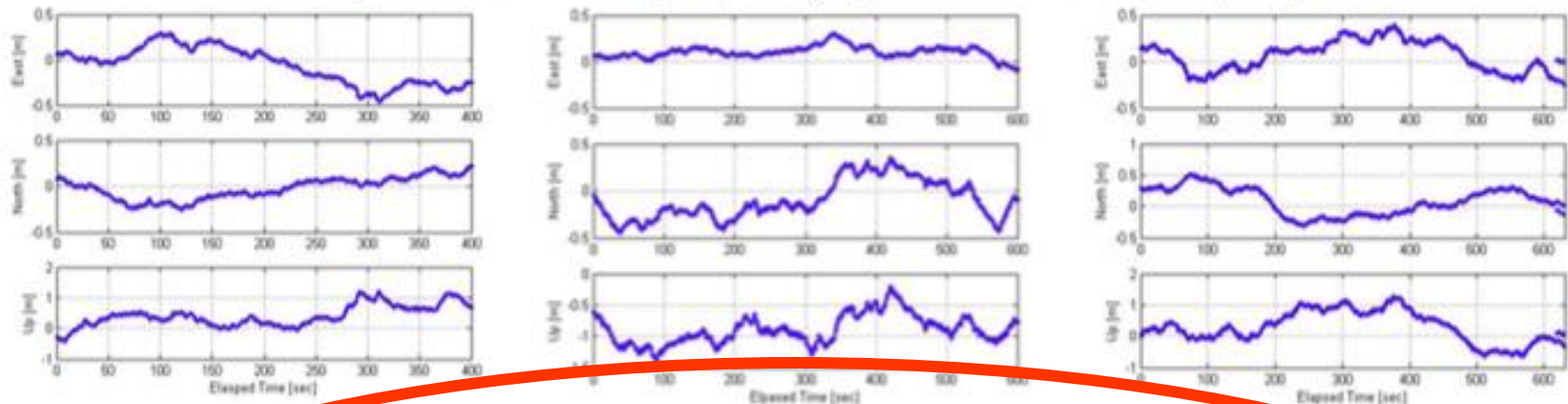
*VIGIL, Inc.*

# *Phase Residuals*

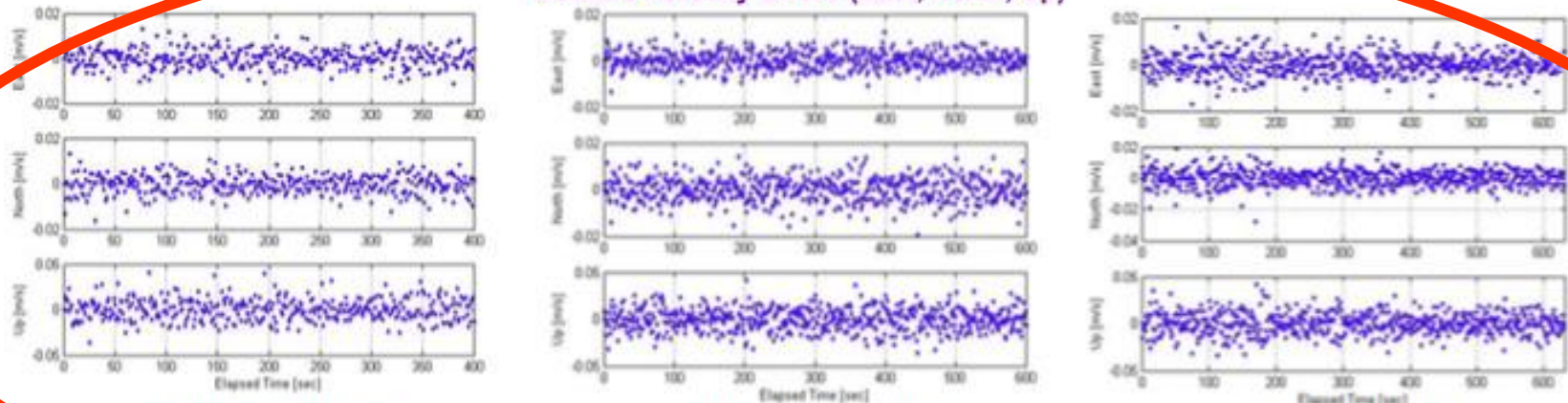


# Flight Test Results – Error Plots

Separation Vector Errors (East, North, Up) – Carrier-smoothed Code (T-20s) on



Relative Velocity Errors (East, North, Up)



Head-on Traffic

Overtaking Traffic

Crossing Traffic

# RECEIVERS SEPARATED by SHORT BASELINE

----- Direction of Vector S from SV to mid-baseline

Ref. Location of  
RCVR #0 (Origin)

Offset Location  
of RCVR # 1

Notation :

$$\mathbf{1}_s = \mathbf{S}/|\mathbf{S}|$$

$B_0 B_1$  =RCVR biases

$C_0 C_1 C_s$  =Clock errors

$M$  =Multipath

$N$  =Noise

$Q$  =Quantiz.

O

I

|

|

|<----- baseline R ----->|

Equations for pseudoranges - from -

$$\text{OFFSET: } (\mathbf{R} - \mathbf{S}) \cdot \mathbf{1}_s + IONO + TROPO + B_1 + C_1 - C_s + M_1 + N_1 + Q_1$$

$$\text{ORIGIN: } (-\mathbf{S}) \cdot \mathbf{1}_s + IONO + TROPO + B_0 + C_0 - C_s + M_0 + N_0 + Q_0$$

---


$$\text{DIFF: } \mathbf{R} \cdot \mathbf{1}_s + B + C + M + N + Q$$

- $\Delta(IONO) \doteq 0$
- If  $\Delta(TROPO) \neq 0$  adjust for altitude & wet / dry
- Eliminate  $B$  &  $C$  by subtracting DIFFs from two SVs
- Sync requirements  $\rightarrow$  knowledge (not control) of meas. timing

## PERFORMANCE ISSUES

Error growth for 90 sec to closest approach:

ADSB:  $10 \text{ m/sec} * 90 \text{ sec} = 900 \text{ meters}$

OhioU:  $1 \text{ cm/sec} * 90 \text{ sec} < 1 \text{ meter}$

No ground station would be needed **IF**

*RELATIVE* differential operation

*BUT* recent panel gave no assurance

Decades-old advocacy

flight-validated and documented

Further – Ultratight (~20 dB) – why not routine

Reason : no "hooks"

More applications make the need more urgent

pedestrian nav, UAVs, ...

## NO SUCH THING as a

- Latitude & Longitude meter
- Velocity vector meter

Ancient mariners knew, as we do –  
**DEDUCE** coordinate **HISTORY** from measurements

**IONJ99** opens with 8 reasons for *Measurements*  
of Satnav (pseudorange, carrier phase)  
applicable to DME, eLoran, radar, ... *all*

GPSWorld Dec 2009, pp. 8, 10, 12 : *"The industry can either adopt changes or continue to settle for performance levels at a minor fraction of the intrinsic capabilities available from our present and future systems."*

Dixon et. al., "GNSS Vulnerabilities: Testing the Truth," Coordinates v VIII n3, March 2012, pp. 13-20 :  
*"Do we really need to wait for a catastrophe before taking action against GNSS vulnerabilities ?"*

**LESS VULNERABILITY –  
via LESS *DEMAND* for DATA**

- In addition to (*not in lieu of*) smart-*rf* measures :
- IMU aiding (cm/sec even with old MotionPak)
- Single measurement RAIM
- Interoperability/Interchangeability ⇒ InterFACE  
– with *all* sensors – *easy*
- Optimize *dynamics* as well as position
- Recognize that dynamics often warrant *priority*
- vanGraas/Pelgrum road test
- By all means, backup -- and, still --  
*use* GNSS when available, even fragmentary
- No more "GPS vacation"

## **1-sec Changes in Carrier Phase**

- **Ambiguity forever OK**
- **No mask**
- **Discontinuities OK**
- **Immediate reacq**
- **Flight validated**
- **Any channel any constellation**
- **Insensitive to**
  - SV mislocation**
  - nonuniform ellipsoid models**
  - nonuniform time ref**
- **Geometry benefit**



## **CURRENT POPULAR APPROACHES**

**Full fix + RAIM "on silver platter" every time**

**No access to data that would enable flexibility**

**No hooks to enable ultratight coupling**

**Proprietary**

**Integrity monitor + tight coupling + diff :  
INTERNAL (if at all)**

**EVERY CHANGE INCURS FULL COST**

# **PARTIAL HISTORY of ADVOCACY**

**NAECON 77**

**JLFvG GPS-90**

**NAECON 93**

**AEEC**

**GPSWorld, InsideGNSS**

**BigBook**

**C-A seminar, ION-GPS-2000**

**FAA/ SC 186**

**ION (e.g., IONJ Fall `99)**

**Coordinates zine**

**IJUSENG – v1 n1, pages 1-8**

**YouTube**

## **RECOMMENDATIONS**

**Raw data across-the-board**

**Keep the good while rejecting the bad**

**Every combination federated + integrated  
available in parallel**

**Exploit well-known capabilities**

**Capitalize on less-known innovations**

**ENORMOUS gains**

**performance + economy + flexibility**

**Intro of presentation at ION-GNSS 2008 –  
<http://jameslfarrell.com/wp-content/uploads/2010/05/robust.pdf>**

**The best humanly possible strategy is to deliver whatever performance is reachable from all available information, incomplete as it may be. For decades it has been feasible to combine intermittent partial data – of different types at varying accuracies with different sensitivities from different directions at different times – and extract all benefit offered. Decisions adopted herein offer no more and no less than that.**

# URLS

**A subset of my relevant material appears below. Further analytical development is presented among the chapters of *GNSS Aided Navigation & Tracking (2007)*, described briefly at <http://jamesfarrell.com/wp-content/uploads/2012/03/GPSINS.pdf>, with sample flight validation results at <http://jamesfarrell.com/wp-content/uploads/2010/06/plf1test.pdf>.**

<http://jamesfarrell.com/whats-new-a-pledge-fulfilled/>  
<http://jamesfarrell.com/surveillance/>  
<http://jamesfarrell.com/wanted-precise-velocity-manned-and-unmanned/>  
<http://jamesfarrell.com/how-reliable-is-reliable-enough/>  
<http://jamesfarrell.com/how-its-all-flight-validated/>  
<http://jamesfarrell.com/dead-reckoning-by-gps-carrier-phase/>  
<http://jamesfarrell.com/1-sec-carrier-phase-again/>  
<http://jamesfarrell.com/eloran/>  
<http://jamesfarrell.com/check-list-for-designers/>  
<http://jamesfarrell.com/runway-incursions/>  
<http://jamesfarrell.com/in-air-collision-avoidance-moving-forward/>  
<http://jamesfarrell.com/book-on-tracking/>  
<http://jamesfarrell.com/single-measurement-ram/>  
<http://jamesfarrell.com/gpsfft/>  
<http://jamesfarrell.com/kalman-filter-strapdown-imaging-tracking-and-more/>  
<http://jamesfarrell.com/extended-ram-eraim-ion-gps-1992/>  
<http://jamesfarrell.com/kalman-filter-of-suboptimal-does-it-matter/>  
<http://jamesfarrell.com/collision-avoidance/>  
<http://jamesfarrell.com/cartesian/spherical/>  
<http://jamesfarrell.com/the-pace-of-change-in-the-industry/>

## PDFS

<http://jamesfarrell.com/wp-content/uploads/2010/07/p1robust.pdf> (one page)  
<http://jamesfarrell.com/wp-content/uploads/2013/07/DGPS1A.pdf> (one page)

## COLUMNS AND MANUSCRIPTS

<http://www.insidegnss.com/node/3492>  
<http://www.insidegnss.com/node/842>  
<http://mycoordinates.org/more-gps-or-smarter-gps/>  
<http://jamesfarrell.com/wp-content/uploads/2015/02/JUSEng1.pdf>  
<http://gpsworld.com/transportationaviationexpert-advice-availability-gaps-solutions-aviation-9182/>  
<http://jamesfarrell.com/wp-content/uploads/2010/06/IONGPS90.pdf>  
<http://jamesfarrell.com/wp-content/uploads/2010/05/robust.pdf>  
<http://jamesfarrell.com/wp-content/uploads/2010/05/gnss09.pdf>  
<http://jamesfarrell.com/wp-content/uploads/2012/03/GPSfix.pdf>  
<http://jamesfarrell.com/wp-content/uploads/2010/07/iongps92.pdf>