# SVN 62 L5 carrier phase anomaly(?), (SVN 49 Bonus)

Byron Iijima
Larry Young, Ruth Neilan, Dave Stowers
*Jet Propulsion Laboratory,*
*California Institute Of Technology*
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**NPEF, January 21, 2011**

# Introduction

- SVN 62 is first and only Block IIF satellite launched
- Montenbruck et al (DLR) found a semi-diurnal signature in “tri-carrier multipath combination” for SVN 62
- Most likely source is L5 carrier phase signature?
- What users are affected by L5 phase?

# Outline

- Discuss multipath combinations with L5 (Simsky)
- DLR tri-carrier multipath combination data
- Looking at IGS data
- Due to L5? (or maybe L1&L2)

- SVN 49
- SNR

- Conclusions

# L5

- Frequencies

  L1 = 1575.42 MHz

  L2 = 1227.60

  L5 = 1176.45
- SVN 49 (PRN 1)  Block IIR-M
- SVN 62 (PRN 25)  Block IIF

# About Multipath Combinations

The GPS range observables are

obs(t) = R(t) + k*TEC(t)/F^2 + flat(t)

R(t) = non-dispersive range (geometric range, tropo, clock)

TEC(t) = line-of-sight total electron content

flat(t) = (hardware biases, multipath, antenna pattern, noise, phase windup, 2nd order iono, etc.)

Can make linear combinations of observables where R and TEC contributions cancel:

MP1 = P1 – 4.091 L1 + 3.091 L2

MP2 = P2 – 5.091 L1 + 4.091 L2

# L5 and more multipath combinations

Any trio of observables defines a multipath combination

Unique up to normalization

MP1 = MP(P1,L1,L2) = P1 – 4.09 L1 + 3.09 L2

MP2 = MP(P2,L1,L2) = P2 – 5.09 L1 + 4.09 L2

MP(P1,L1,L5) = P1 – 3.52 L1 + 2.52 L5

MP(P1,L2,L5) = P1 – 19.09 L2 + 18.09 L5

MP(P5,L1,L5) = P5 – 4.52 L1 + 3.52 L5

MP(L1,P2,P5) = L1 – 19.09 P2 + 18.09 P5

Tri-carrier multipath combination (Simsky)

TCMP = MP(L1,L2,L5)

# Tri-carrier multipath (TCMP) combination

Tri-carrier multipath combination (Simsky)

$$TCMP = MP(L1, L2, L5) = \alpha L1 + \beta L2 + \gamma L5$$

$$\alpha = (\lambda_5^2 - \lambda_2^2) / N$$

$$\beta = (\lambda_1^2 - \lambda_5^2) / N$$

$$\gamma = (\lambda_2^2 - \lambda_1^2) / N$$

$$N^2 = (\lambda_5^2 - \lambda_2^2)^2 + (\lambda_1^2 - \lambda_5^2)^2 + (\lambda_2^2 - \lambda_1^2)^2$$

Normalized so that RSS of coefficients is 1.

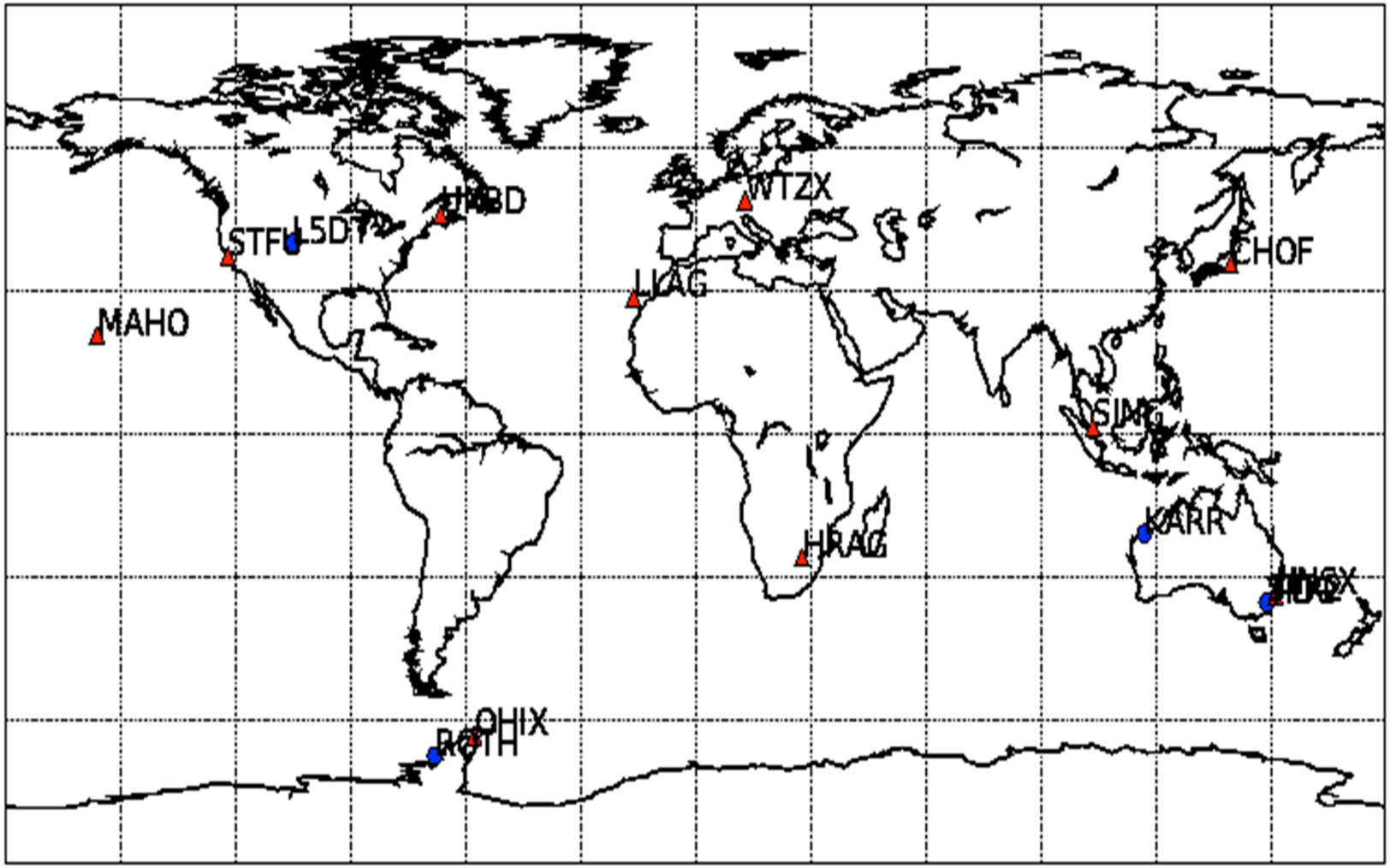
TCMP = 0.1415 L1 – 0.7672 L2 + 0.6257 L5

# SVN 62

- Launched 2010-05-28
- First Block II-F, second GPS with L5
- L5 turned on briefly (5.5 hrs?) 2010-06-17
- L5 turned on permanently 2010-06-28

- DLR has extensive L5 network

# GPS L5 networks



# DLR SVN 62 tri-carrier multipath combo

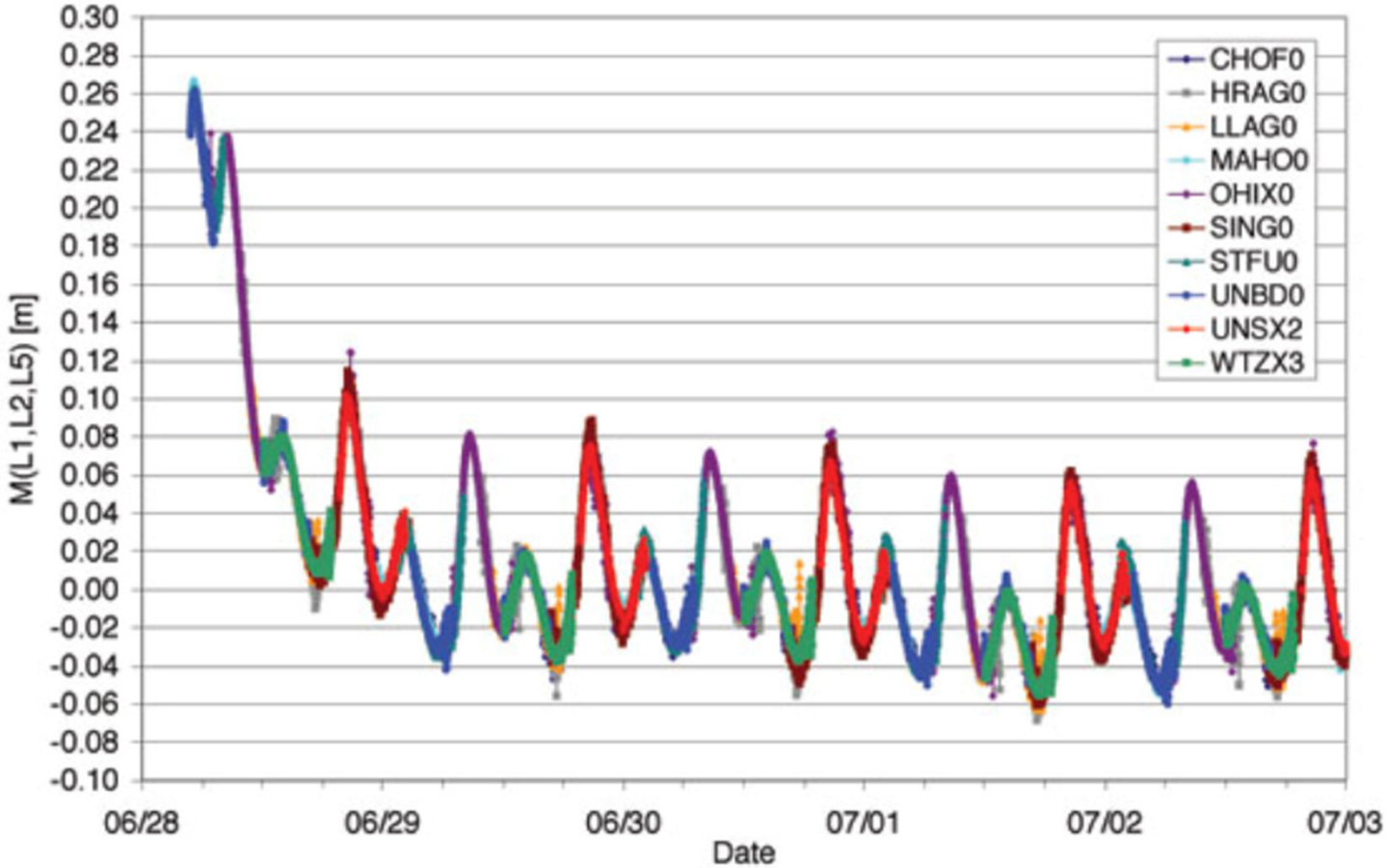



FIGURE 2. Triple-frequency carrier-phase combination (M=0.142·L1-0.767·L2+0.626·L5) for th
has arbitrarily been shifted to obtain a near-zero mean during the final days of the entire arc.

# DLR SVN 62 tri-carrier multipath combo

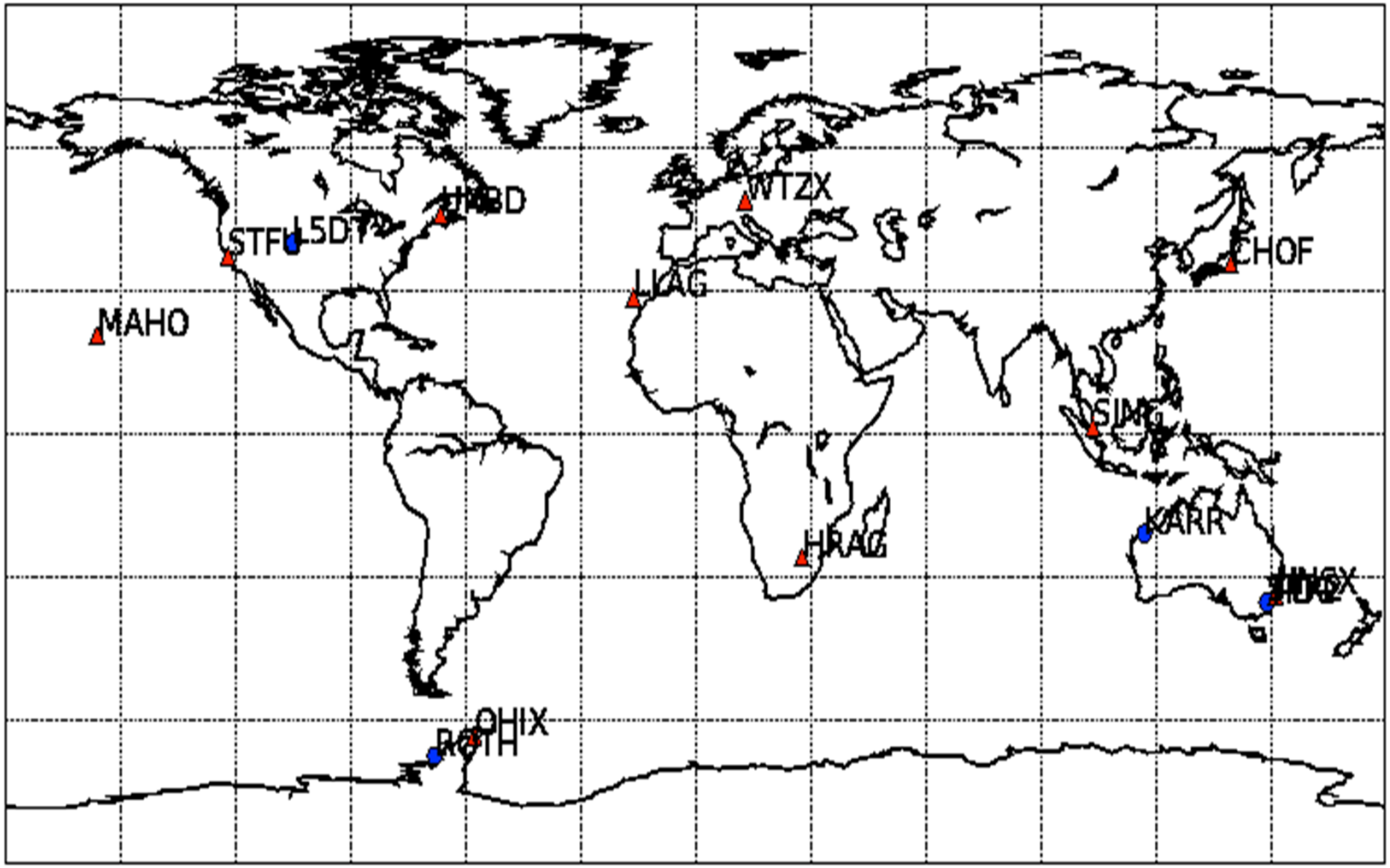
- Continuous temporal signature in TCMP common to all receivers
  - Spacecraft temporal signature
- Semi-diurnal TCMP signature
  - Temperature-driven hardware bias?

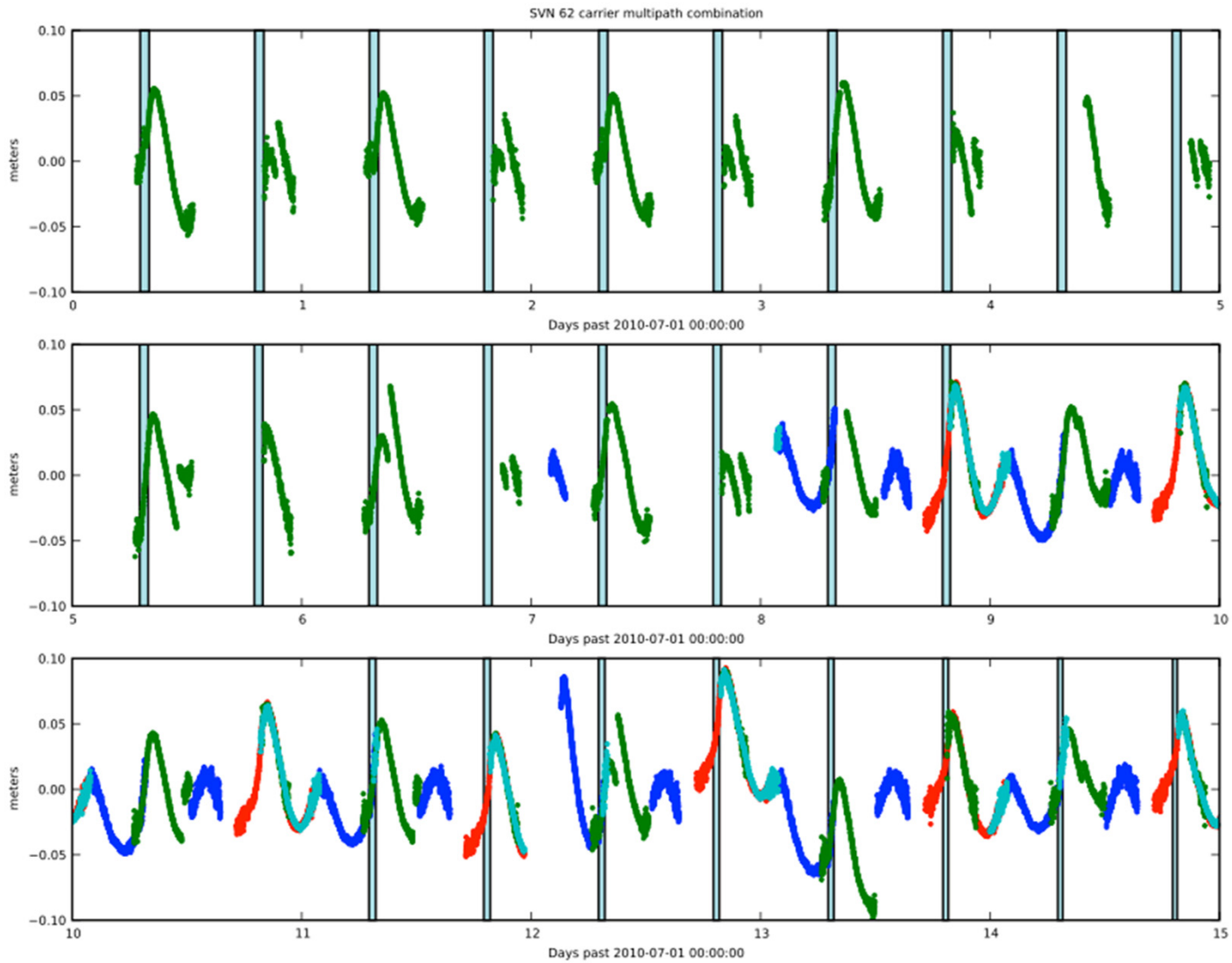
# SVN 62 TCMP longer term (IGS only)

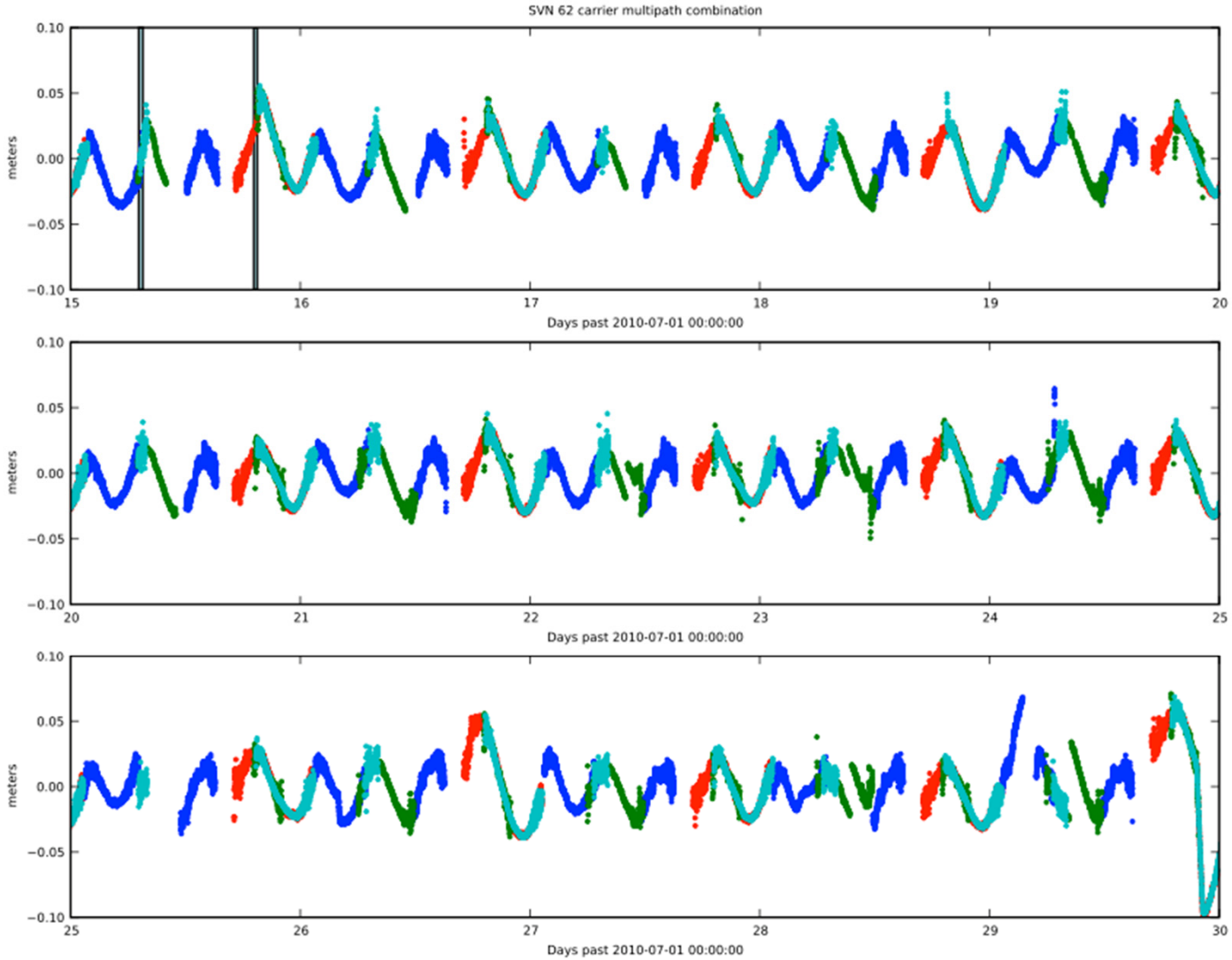
- 2010-07-01 – 2010-08-26

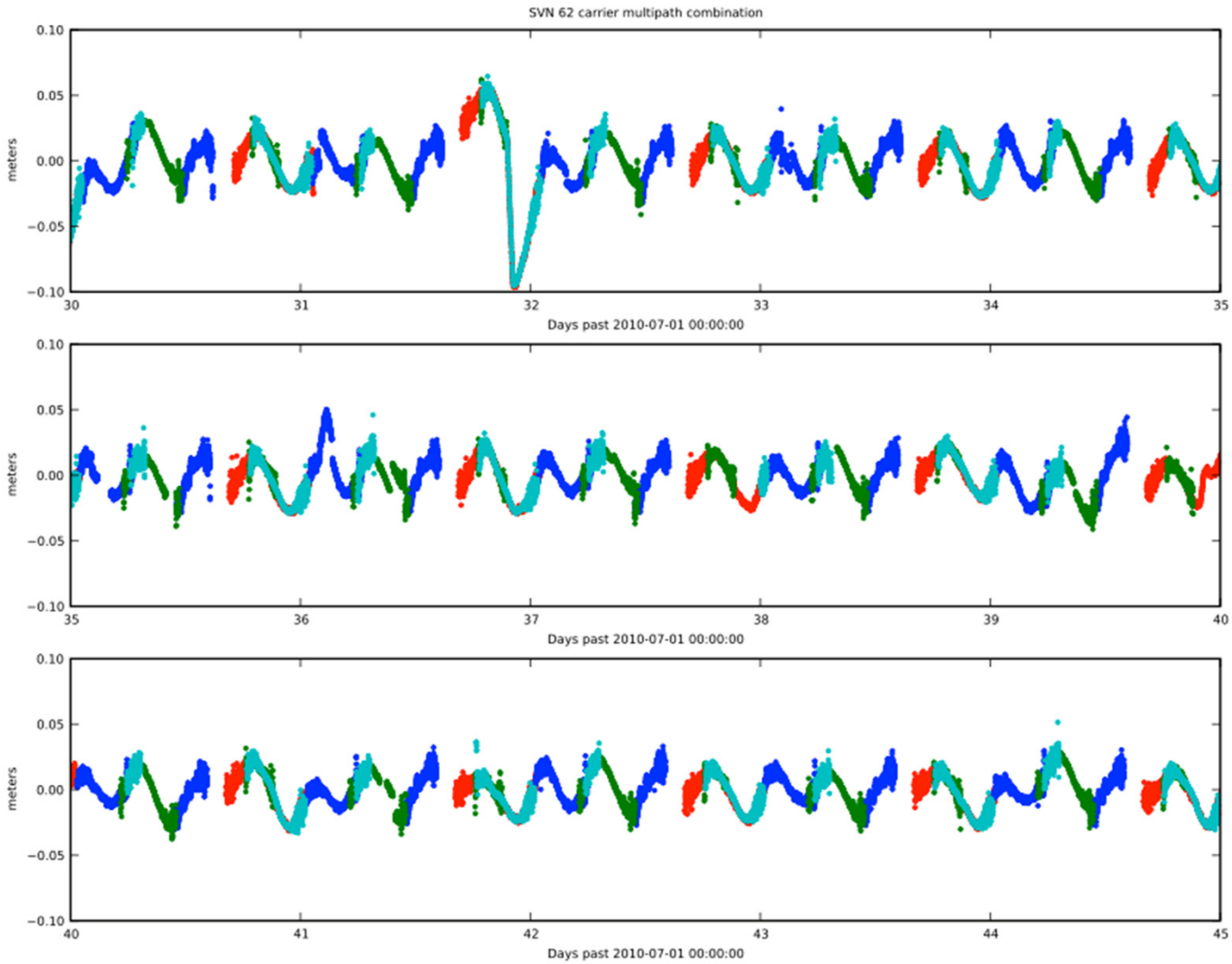
- Daily gap due to paucity of sites

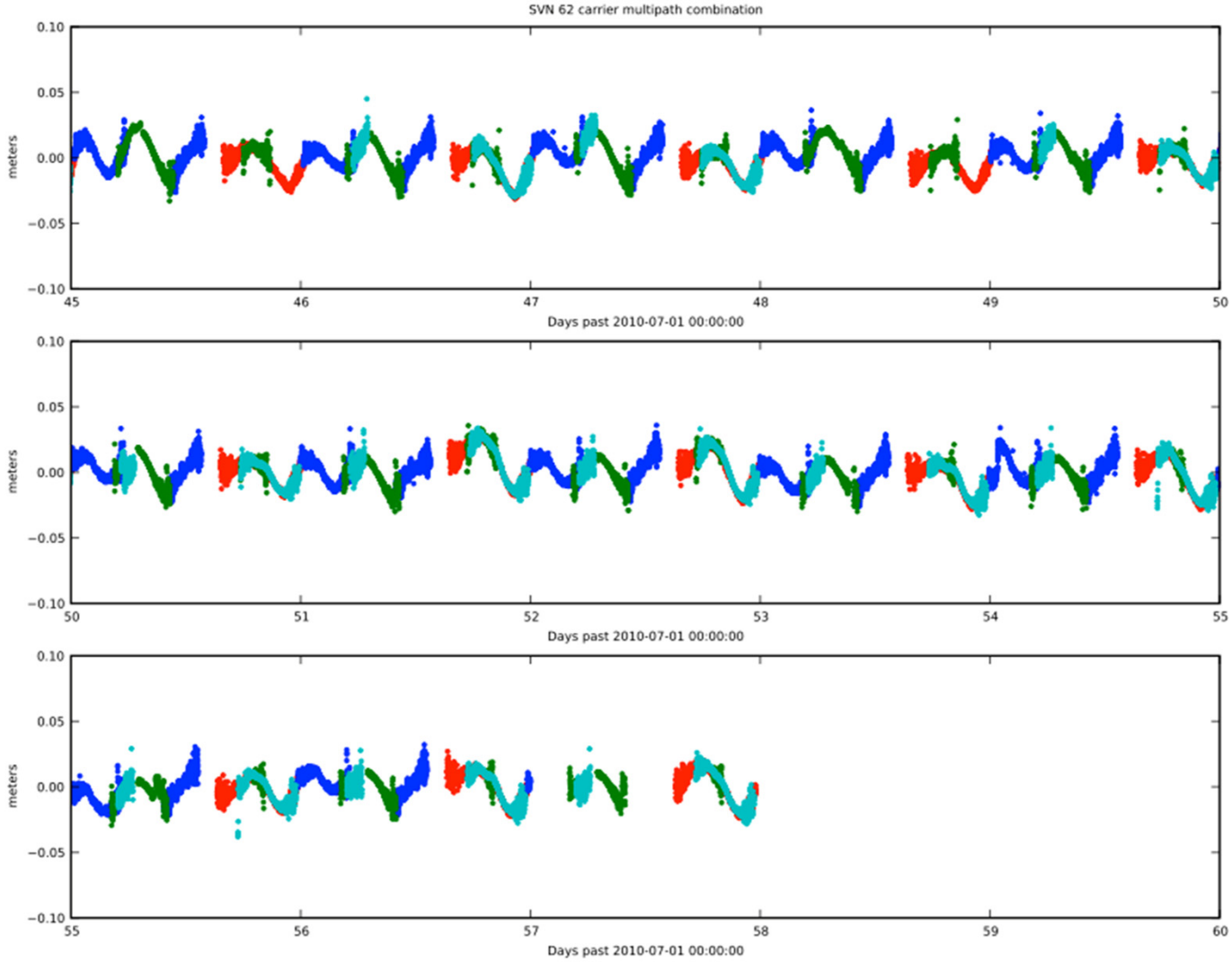
# GPS L5 networks

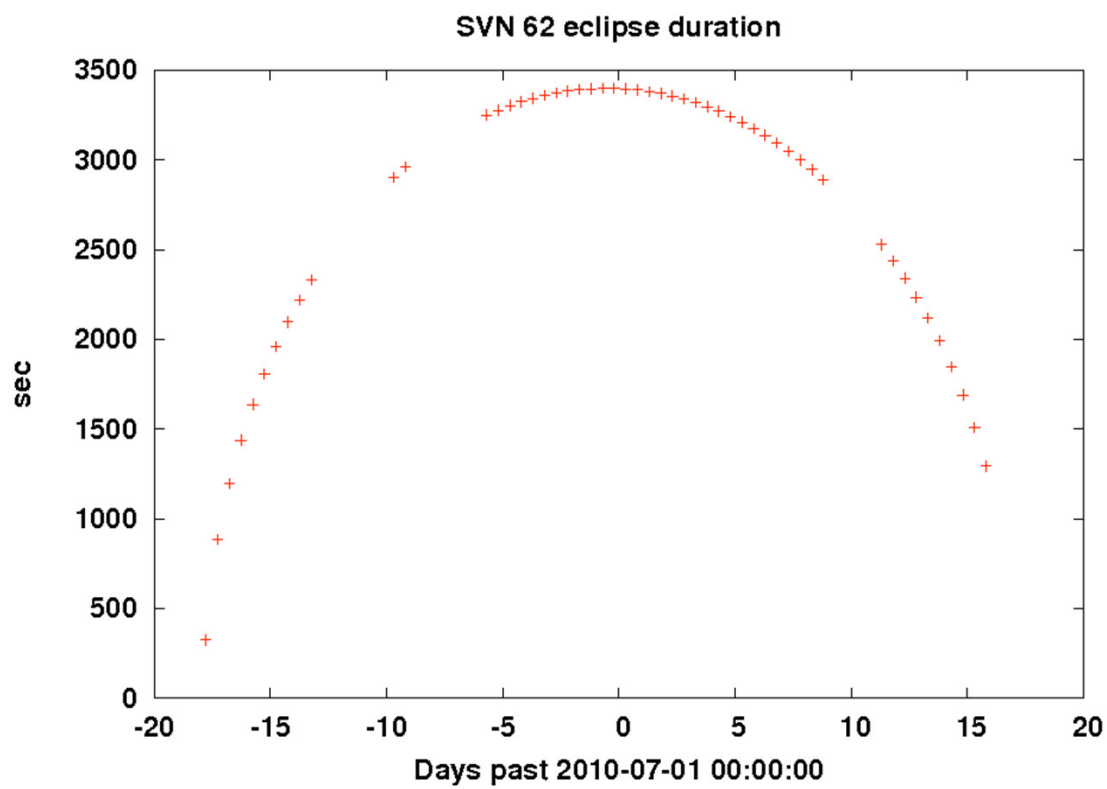


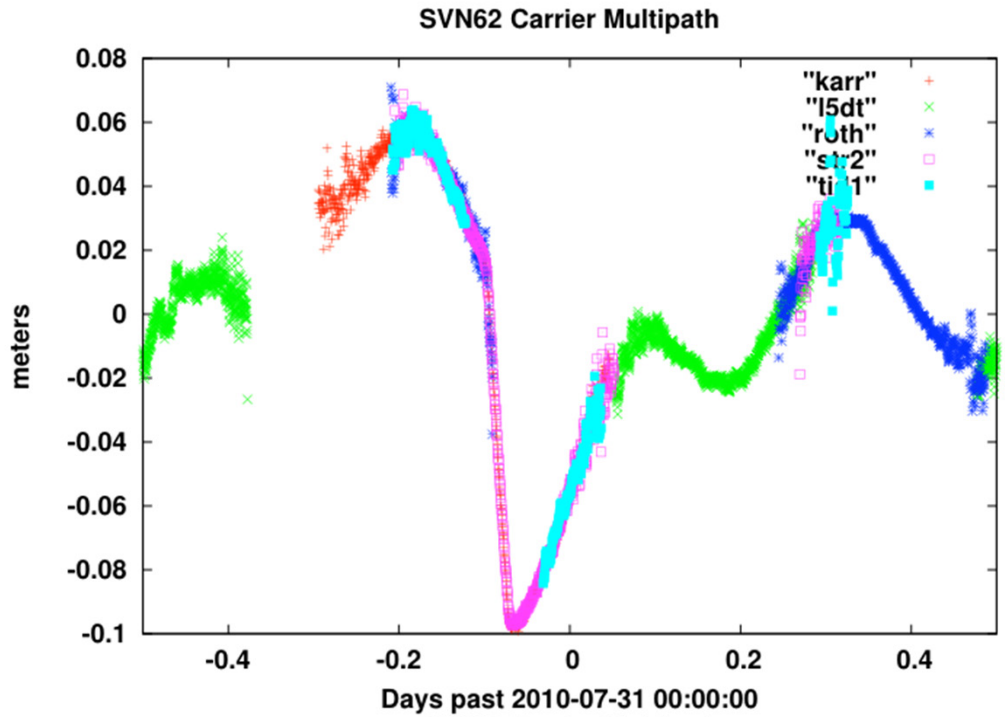

SVN 62 carrier multipath combination
meters
0.10
0.05
0.00
−0.05
−0.10
0
1
2
3
4
5
Days past 2010-07-01 00:00:00
6
7
8
9
10
11
12
13
14
15

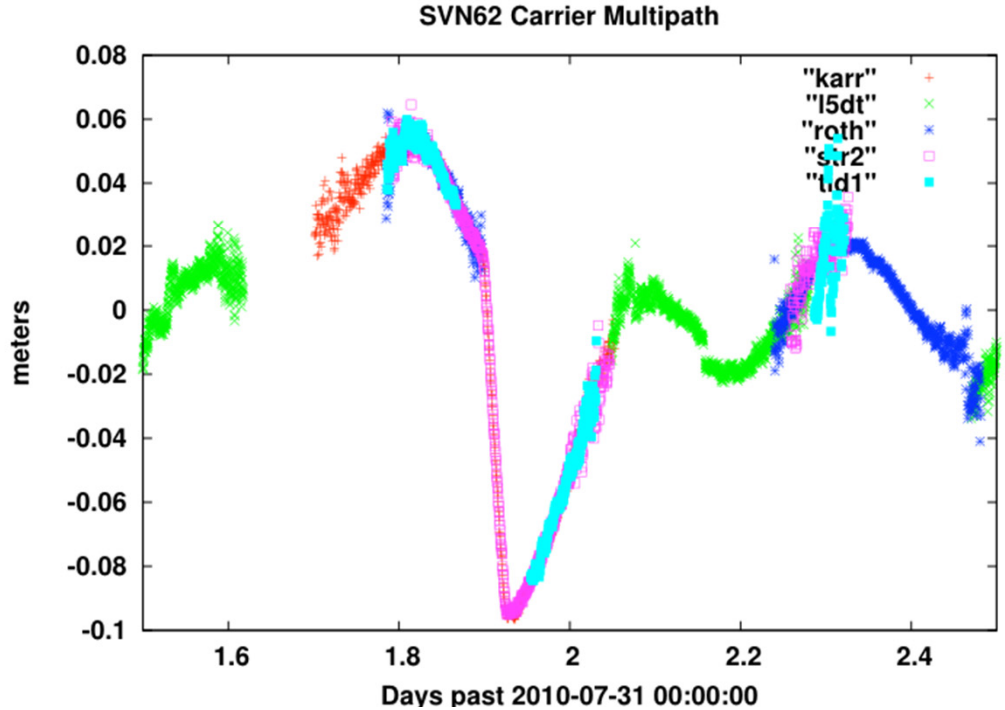

SVN 62 carrier multipath combination
meters
0.10
0.05
0.00
−0.05
−0.10
15
16
17
18
19
20
Days past 2010-07-01 00:00:00
meters
0.10
0.05
0.00
−0.05
−0.10
20
21
22
23
24
25
Days past 2010-07-01 00:00:00
meters
0.10
0.05
0.00
−0.05
−0.10
25
26
27
28
29
30
Days past 2010-07-01 00:00:00

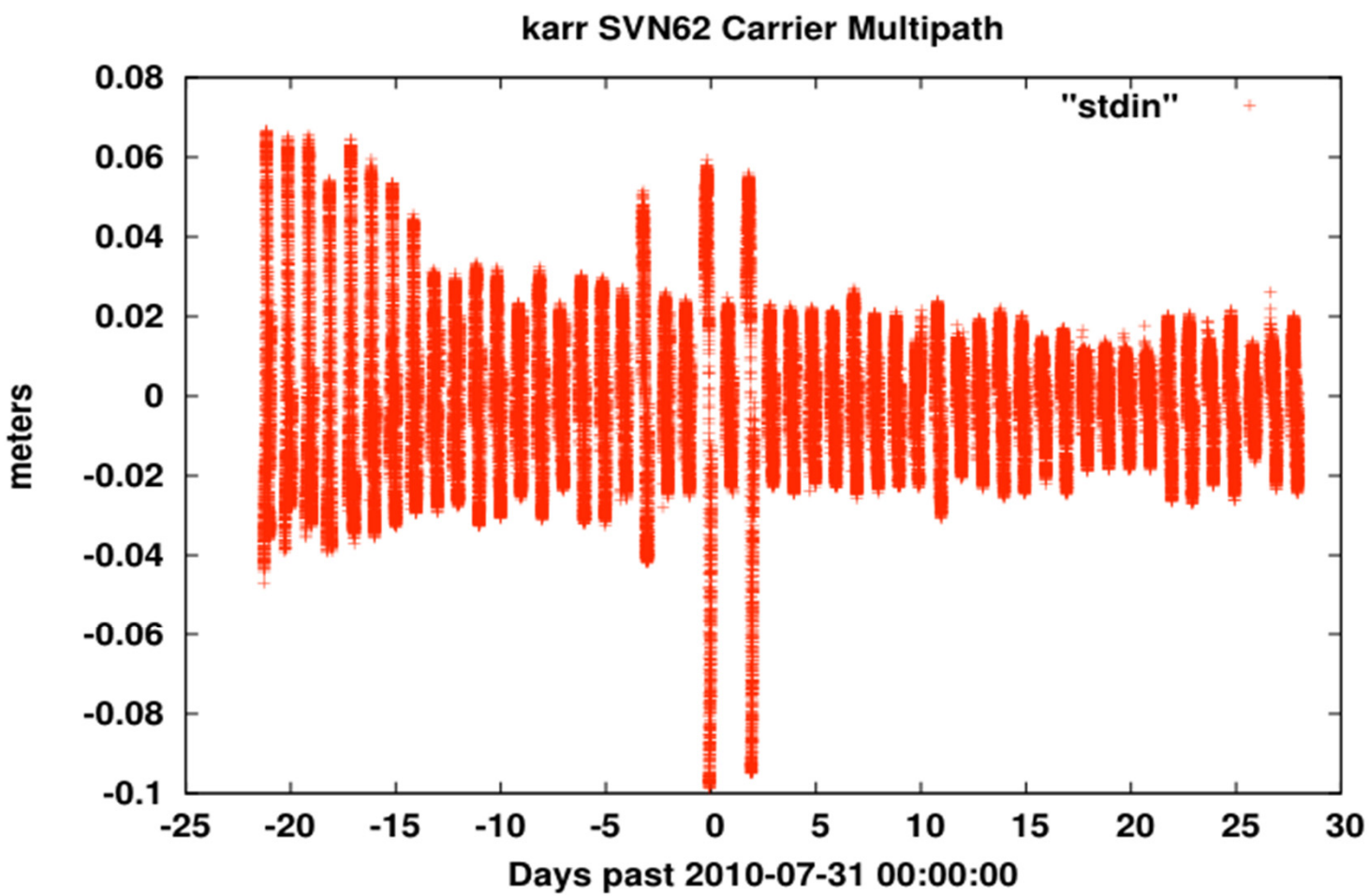

SVN 62 carrier multipath combination
meters
0.10
0.05
0.00
−0.05
−0.10
30
31
32
33
34
35
Days past 2010-07-01 00:00:00
meters
0.10
0.05
0.00
−0.05
−0.10
35
36
37
38
39
40
Days past 2010-07-01 00:00:00
meters
0.10
0.05
0.00
−0.05
−0.10
40
41
42
43
44
45
Days past 2010-07-01 00:00:00


SVN 62 carrier multipath combination
meters
0.10
0.05
0.00
−0.05
−0.10
45
46
47
48
49
50
Days past 2010-07-01 00:00:00
meters
0.10
0.05
0.00
−0.05
−0.10
50
51
52
53
54
55
Days past 2010-07-01 00:00:00
meters
0.10
0.05
0.00
−0.05
−0.10
55
56
57
58
59
60
Days past 2010-07-01 00:00:00


SVN 62 eclipse duration
sec
3500
3000
2500
2000
1500
1000
500
0
-20
-15
-10
-5
0
5
10
15
20
Days past 2010-07-01 00:00:00


SVN62 Carrier Multipath
"karr"
"l5dt"
"roth"
"str2"
"tid1"
meters
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.4
-0.2
0
0.2
0.4
Days past 2010-07-31 00:00:00


SVN62 Carrier Multipath
"karr"
"l5dt"
"roth"
"str2"
"tid1"
meters
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
1.6
1.8
2
2.2
2.4
Days past 2010-07-31 00:00:00


karr SVN62 Carrier Multipath
"stdin"
meters
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
Days past 2010-07-31 00:00:00

# SVN 62 TCMP long term

- Sudden drop in signal size when eclipsing season ends
- Signal continues after eclipsing
- 2 large signal days long after eclipsing over (July 30, Aug 2)
  - Signature on those two days is nearly identical

# Source of SVN 62 TCMP signature

- Not multipath, antenna pattern, windup, 2nd order iono, receiver effects
- Temporal instrumentation phase bias signature on at least one of the frequencies
- Can we attribute to one of the 3 frequencies?
  - Use pseudorange multipath combinations

    MP(P1,L1,L2) = P1 – 4.09 L1 + 3.09 L2

    MP(P1,L1,L5) = P1 – 3.52 L1 + 2.52 L5

    MP(P1,L2,L5) = P1 – 19.09 L2 + 18.09 L5

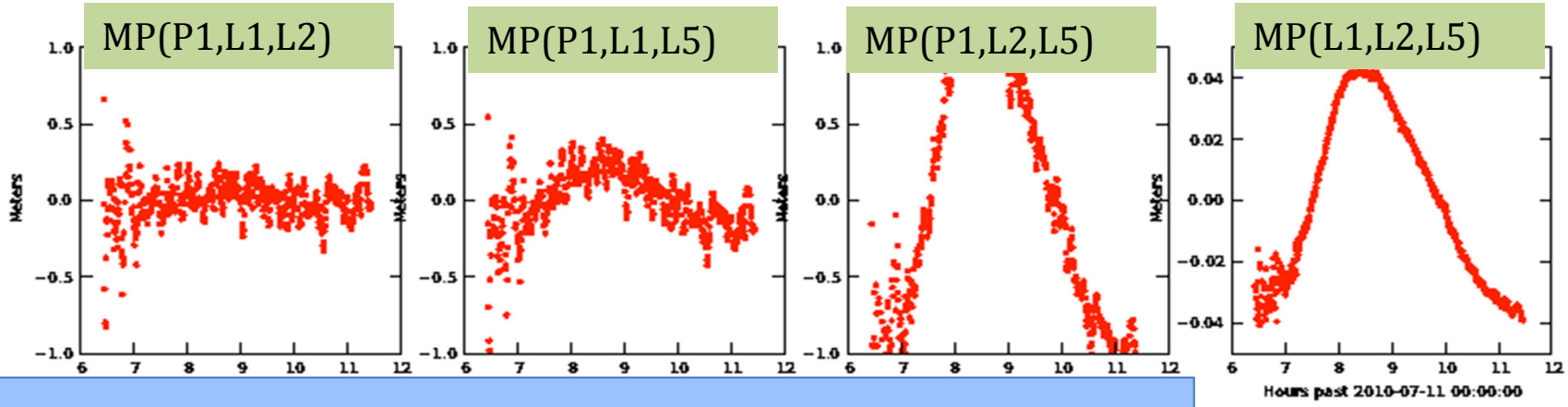
# Source of SVN 62 TCMP signature

- Not multipath, antenna pattern, windup, 2nd order iono, receiver effects
- Temporal instrumentation phase bias signature on at least of the frequencies
- Can we attribute to one of the 3 frequencies?
  - Use pseudorange multipath combinations

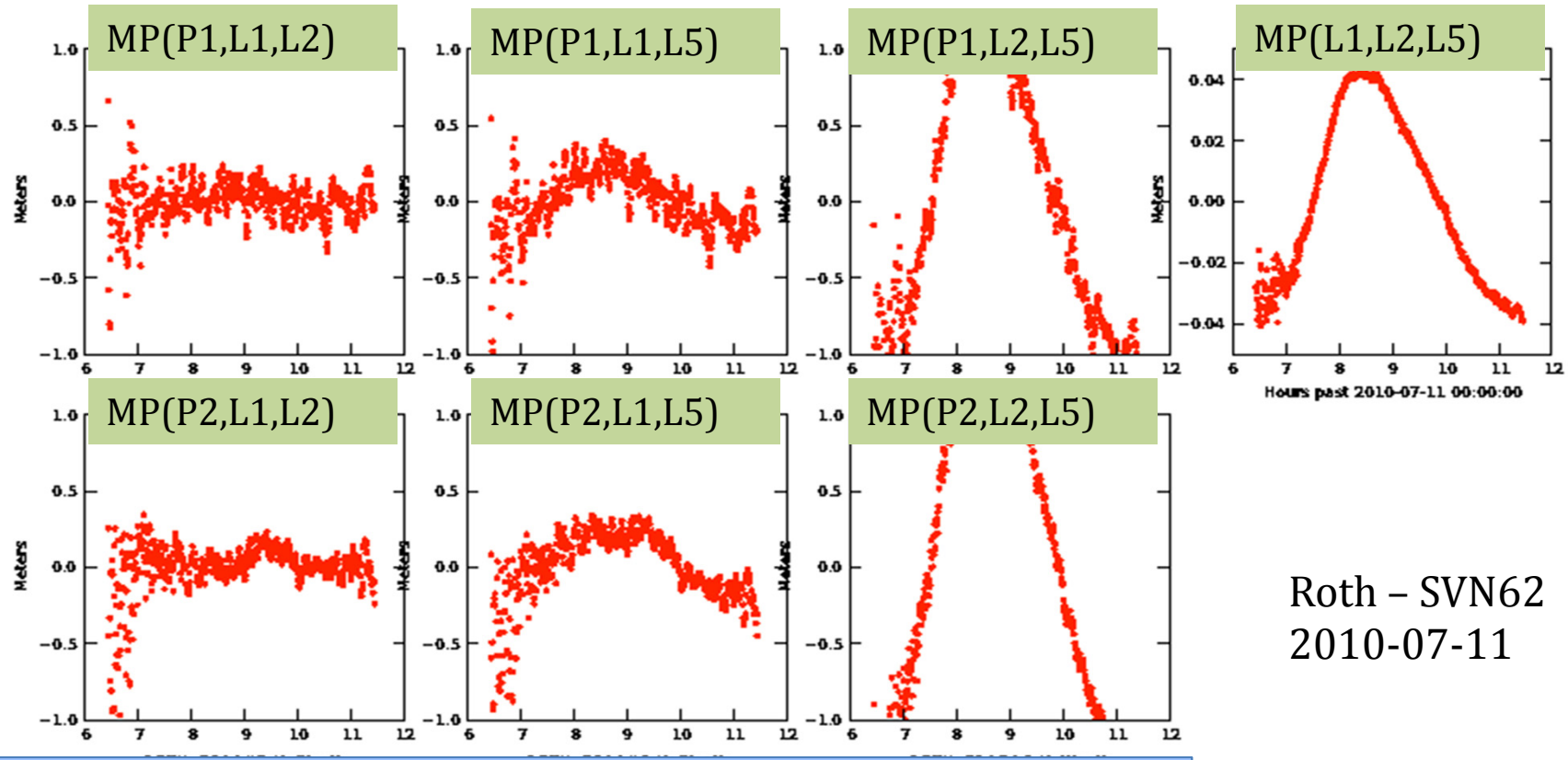
$$MP(P1,L1,L2) = P1 - 4.09\ L1 + 3.09\ L2$$
$$MP(P1,L1,L5) = P1 - 3.52\ L1 + 2.52\ L5$$
$$MP(P1,L2,L5) = P1 - 19.09\ L2 + 18.09\ L5$$

$$MP(P2,L1,L2) = P2 - 5.09\ L1 + 4.09\ L2$$
$$MP(P2,L1,L5) = P2 - 4.34\ L1 + 3.43\ L5$$
$$MP(P2,L1,L5) = P2 - 23.51\ L2 + 22.51\ L5$$

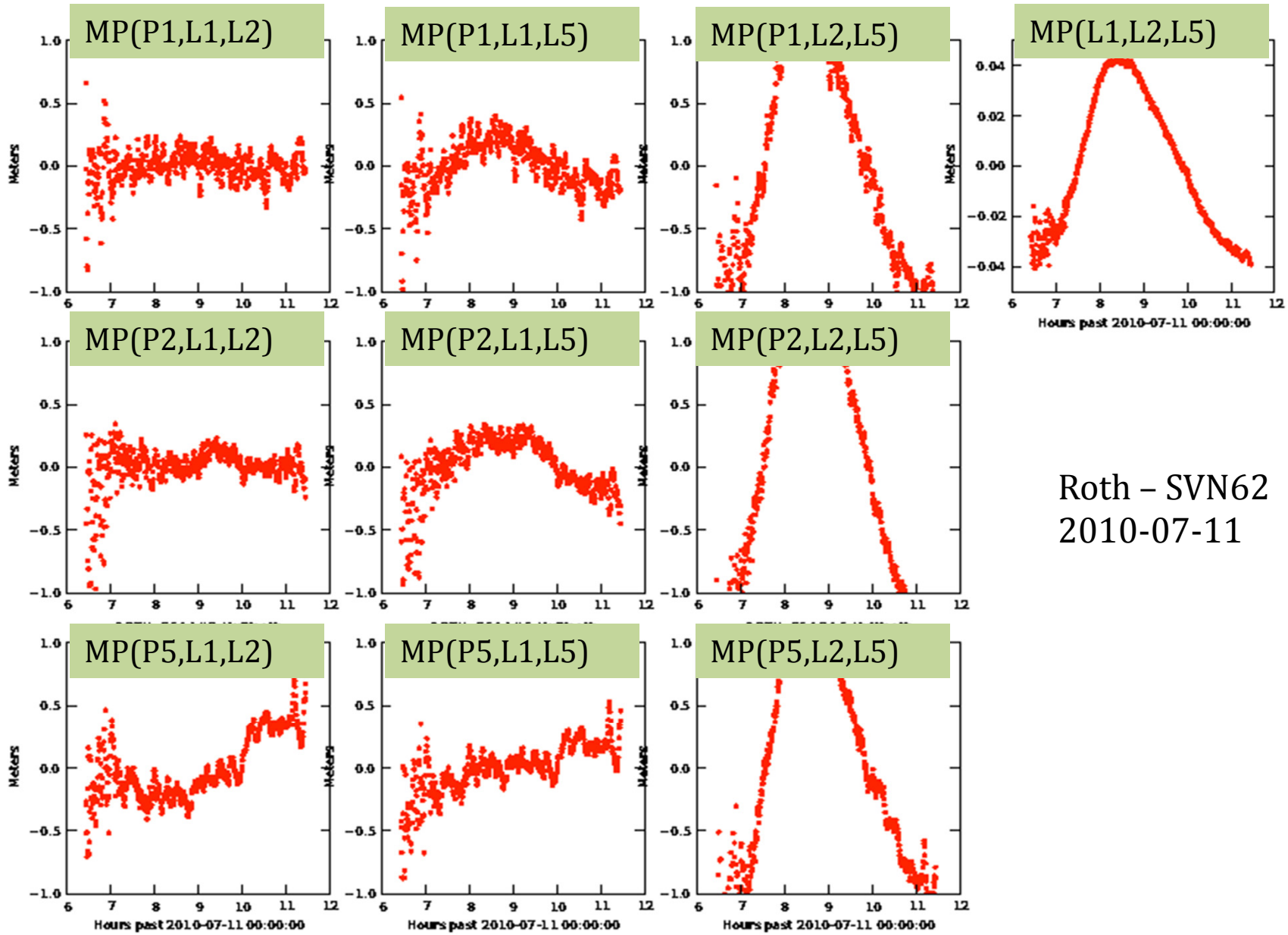
$$MP(P5,L1,L2) = P5 - 5.32\ L1 + 4.32\ L2$$
$$MP(P5,L1,L5) = P5 - 4.52\ L1 + 3.52\ L5$$
$$MP(P5,L2,L5) = P5 - 24.51\ L1 + 23.51\ L5$$




Roth – SVN62
2010-07-11




Roth – SVN62
2010-07-11

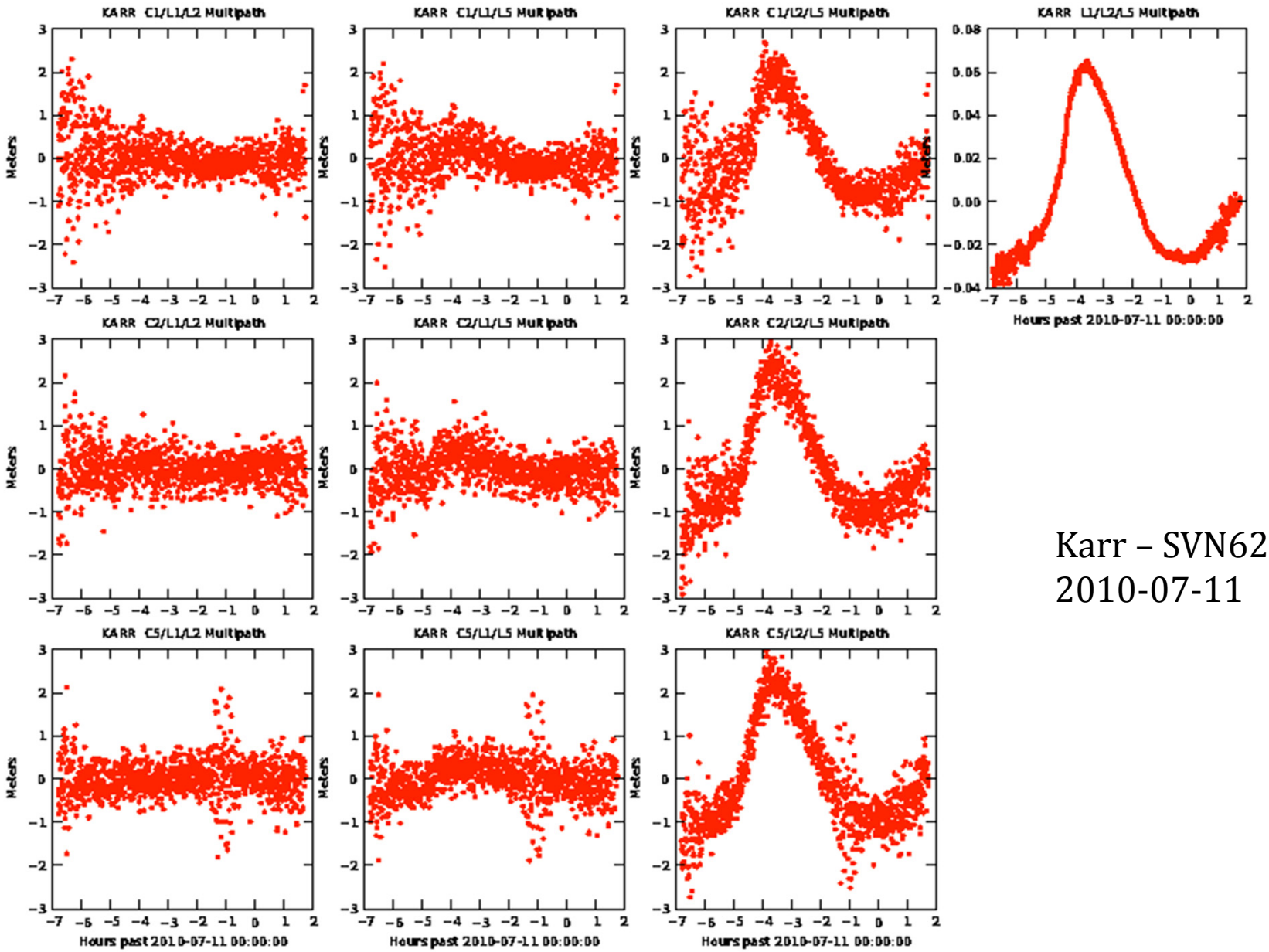



Roth – SVN62
2010-07-11

# Source of SVN 62 TCMP signature

- Looking at data the first row it's easy to imagine that all the TCMP signature is coming from L5, and that it is affecting the multipath calculation in MP(P1,L1,L5) and MP(P1,L2,L5), but not MP(P1,L1,L2).
- Looking at the data in the second row, one thinks the same thing.
- The third row is not so clear: It could be L2 as well.

- Reason – Separate location of L5 hardware?




Karr – SVN62
2010-07-11

# Source of SVN 62 TCMP signature

- To get a clearer picture of which frequency the TCMP signature is coming from, I tried “correcting” the L1, L2, or L5 phase one at a time, and seeing what corrected the MP plots best

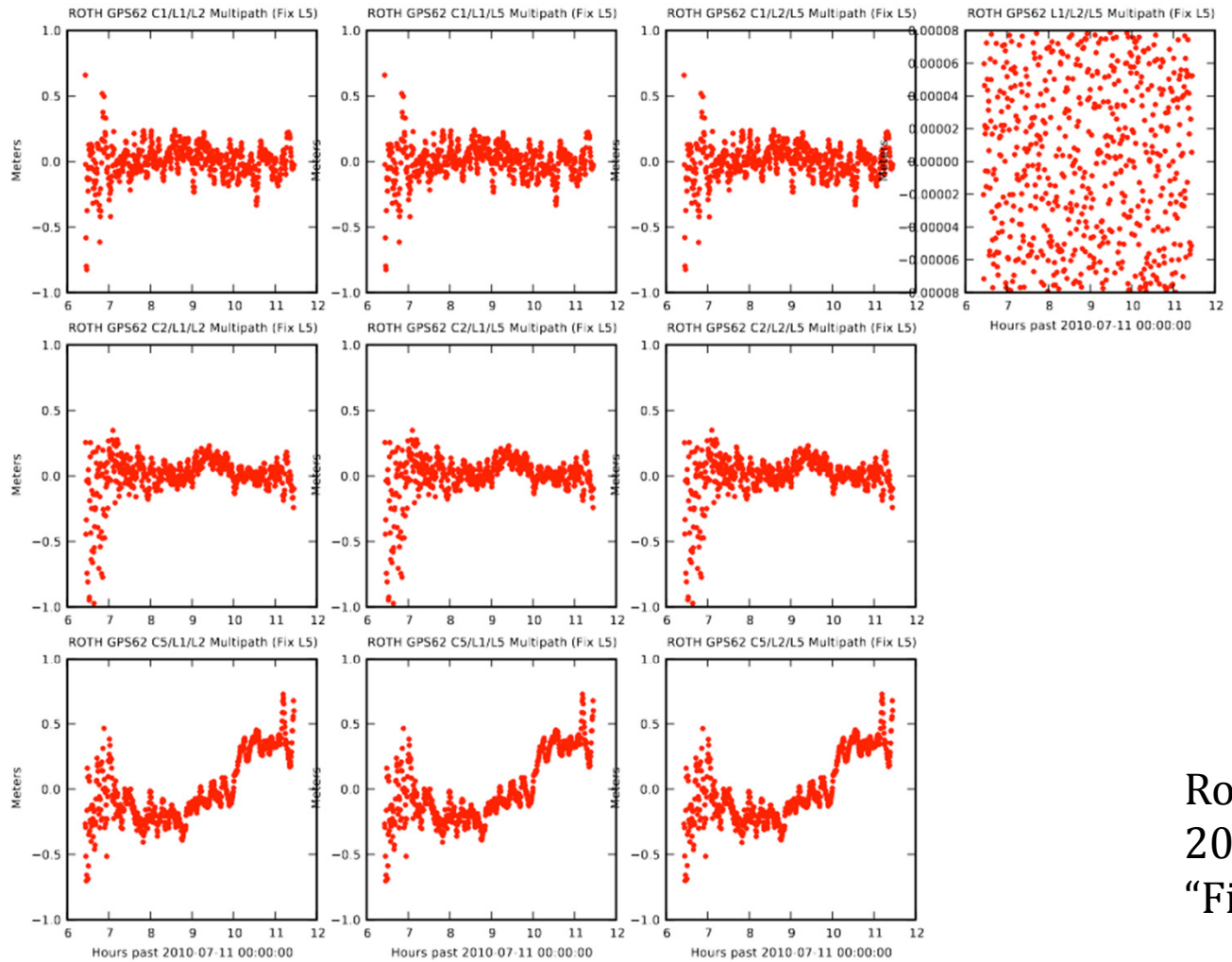
# Source of SVN 62 TCMP signature

Suppose the TCMP signature were due solely to an flaw in L5

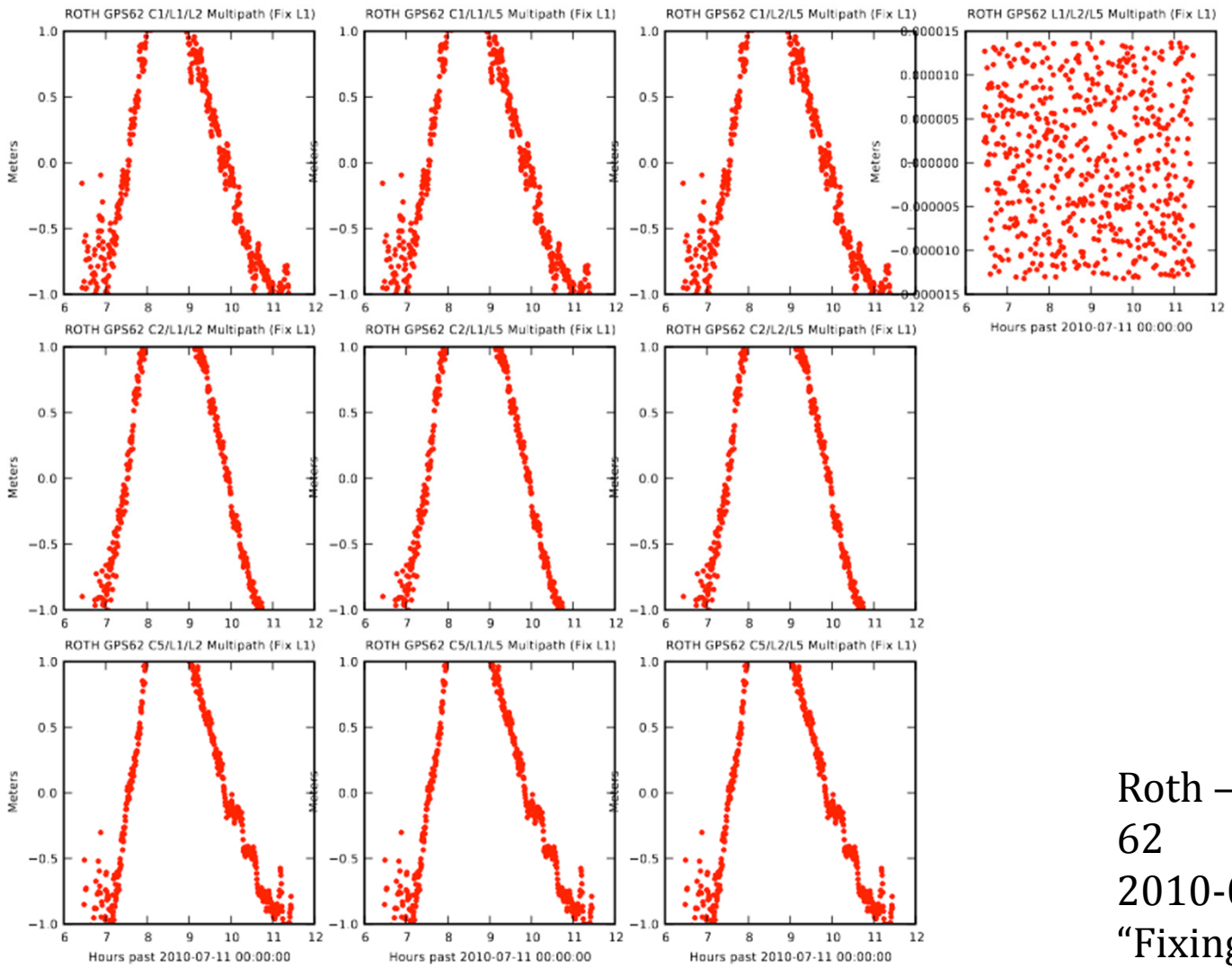
$$TCMP = 0.14L1 - 0.77L2 + 0.63L5 = 0.63\Delta L5$$

$$\Delta L5 = TCMP / 0.63$$

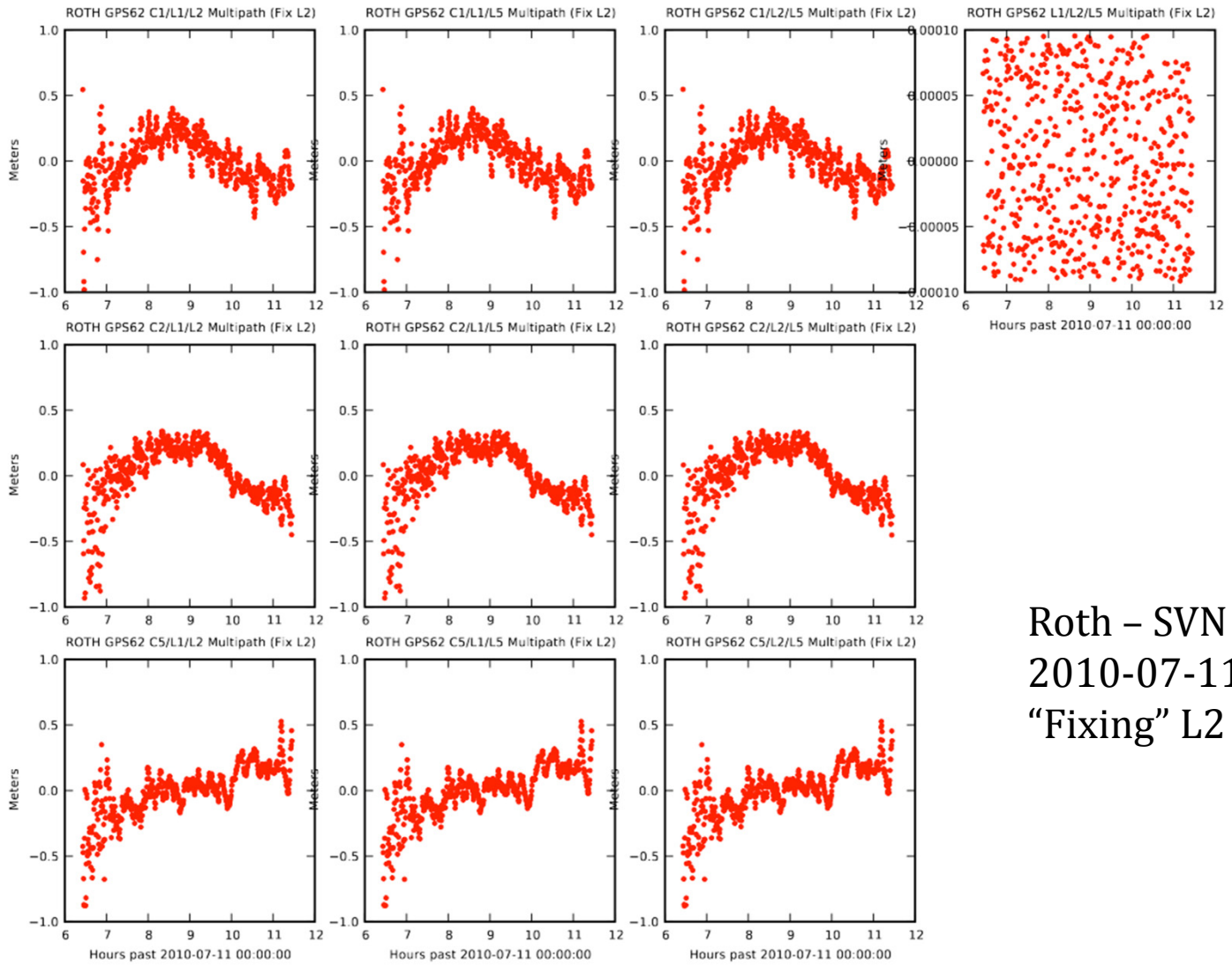
$$L5_{fixed} = L5 - \Delta L5 = L5 - TCMP / 0.63$$




Roth – SVN 62
2010-07-11
“Fixing” L5




Roth – SVN 62
2010-07-11
“Fixing” L1




Roth – SVN 62
2010-07-11
“Fixing” L2

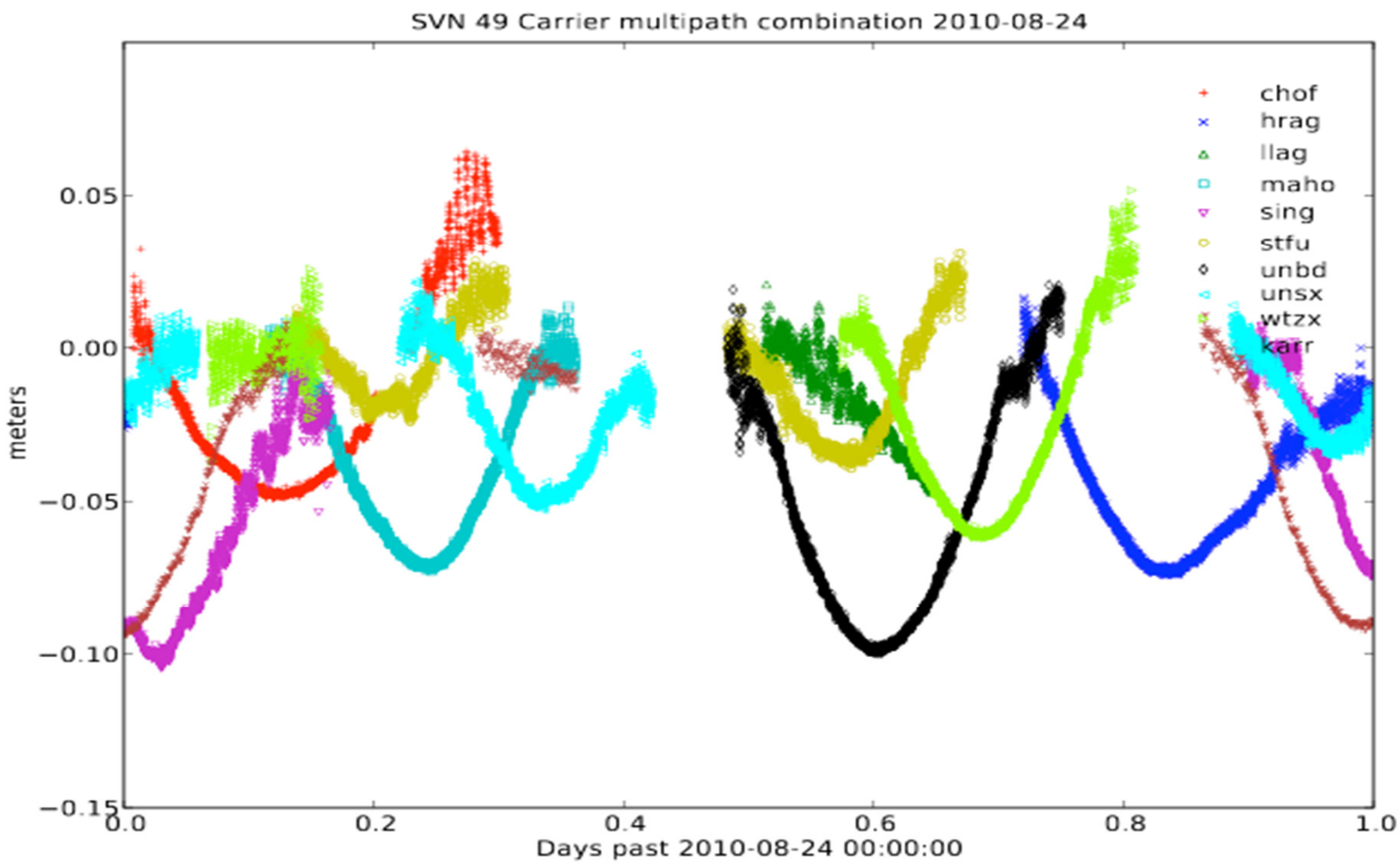
# Source of SVN 62 TCMP signature

- “Fixing” L1 makes everything worse
- “Fixing” L5 seems to remove the TCMP signature from the multipaths the best

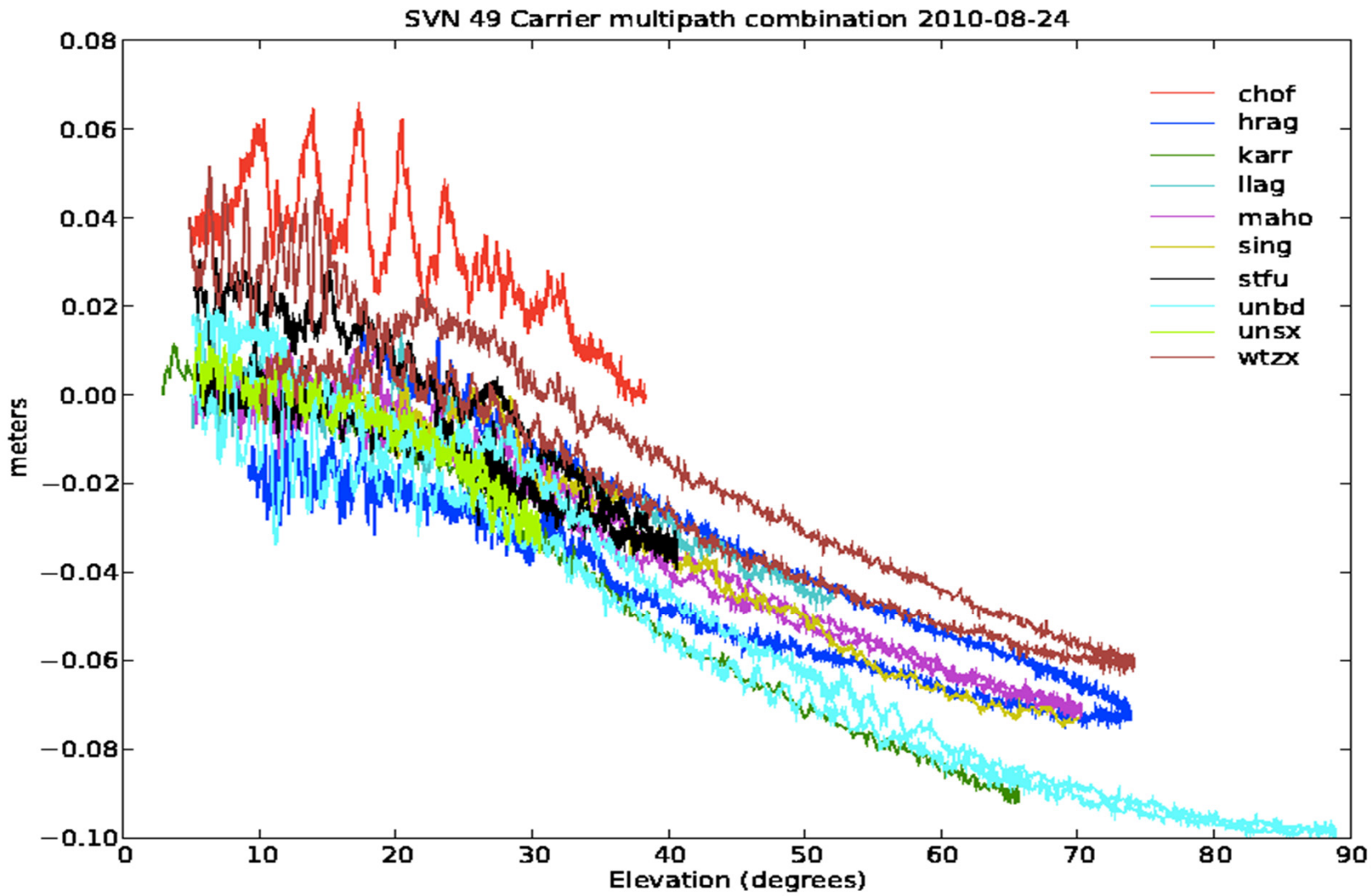
# SVN 49 TCMP signature

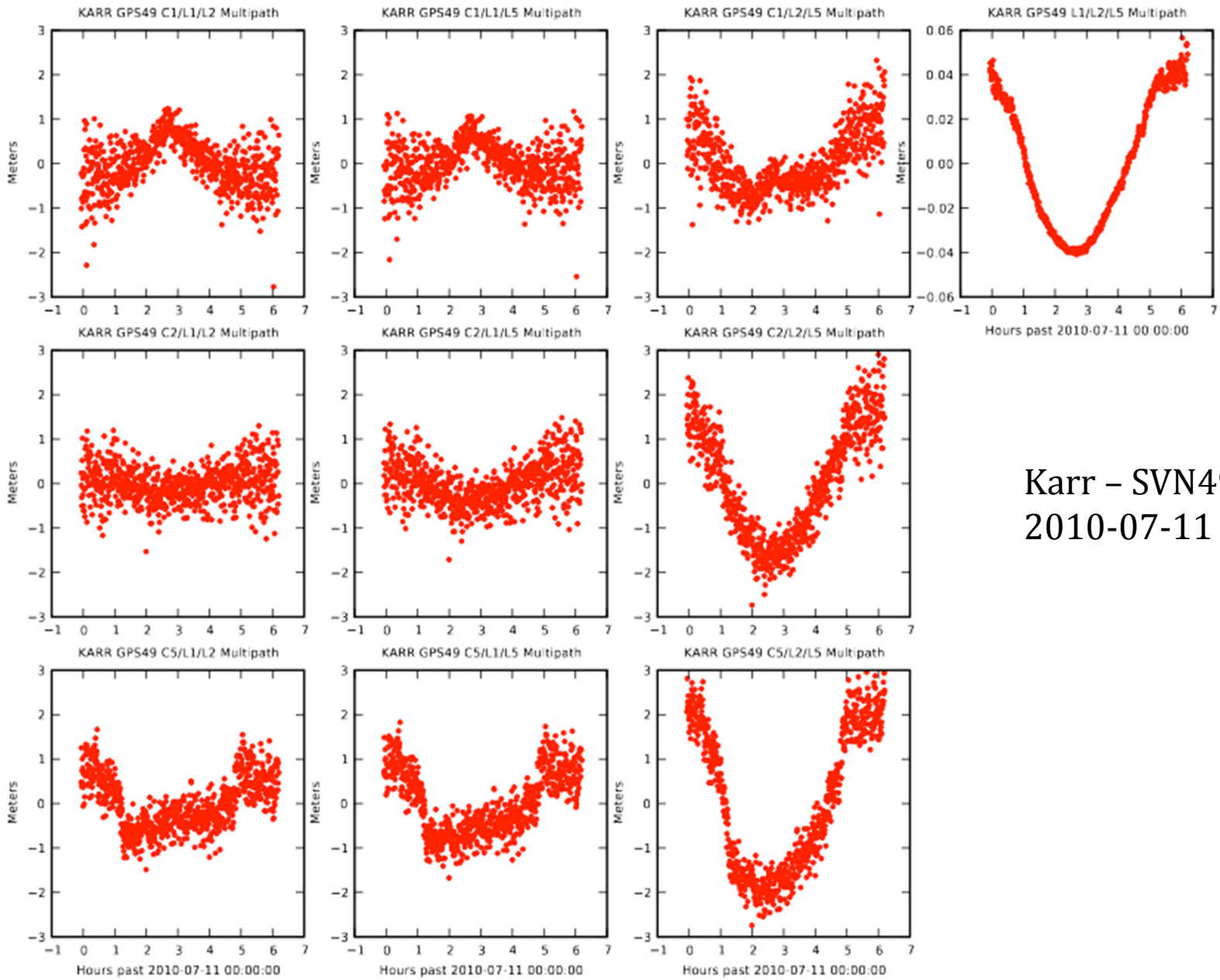
- SVN 49 signature is similar in size to SVN 62
- Very different otherwise
  - Not continuous across stations
  - Strong function of elevation/nadir (no surprise?)
- Any azimuthal or temporal signature is smaller.

# SVN 49 TCMP signature

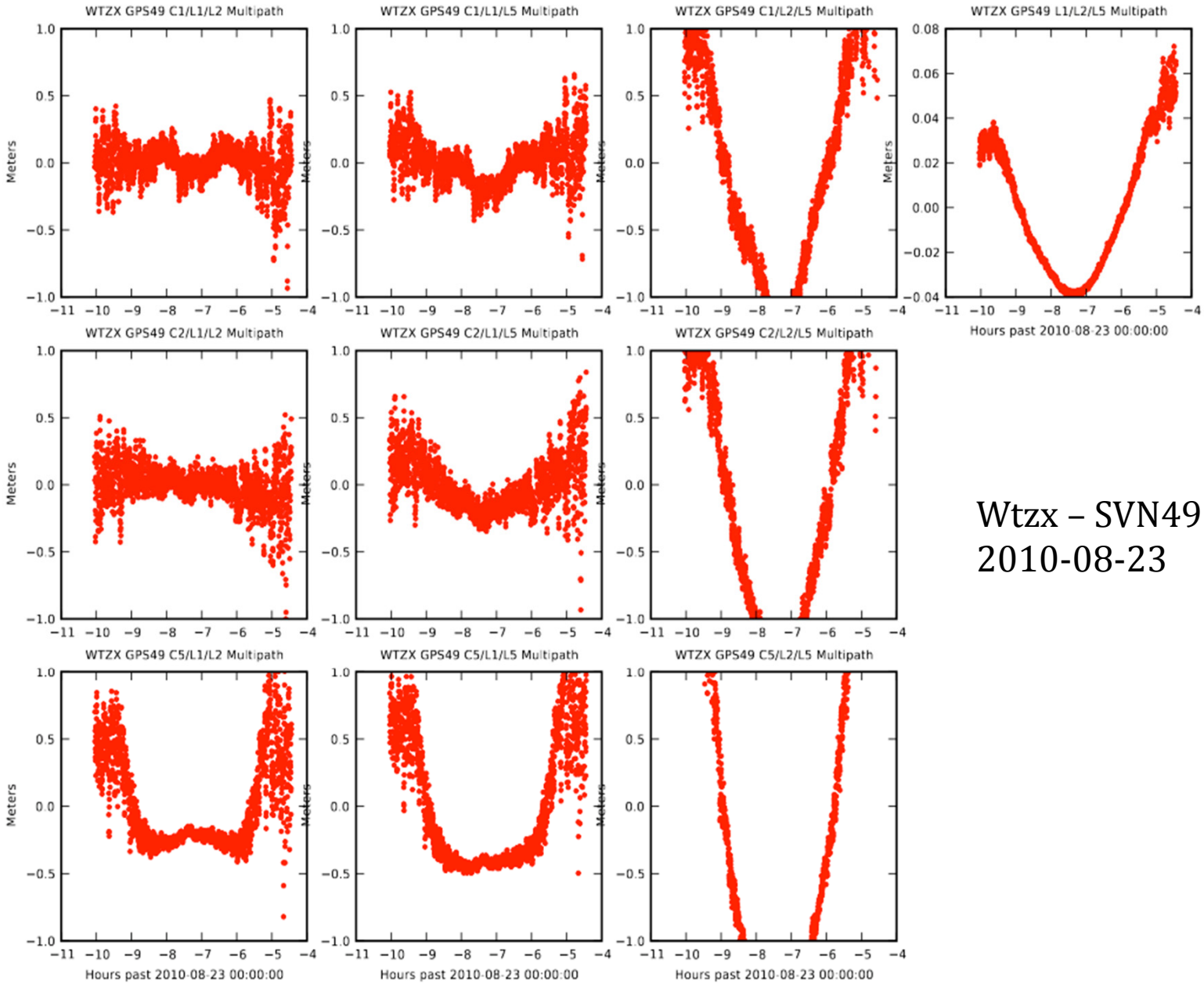


# SVN 49 TCMP signature

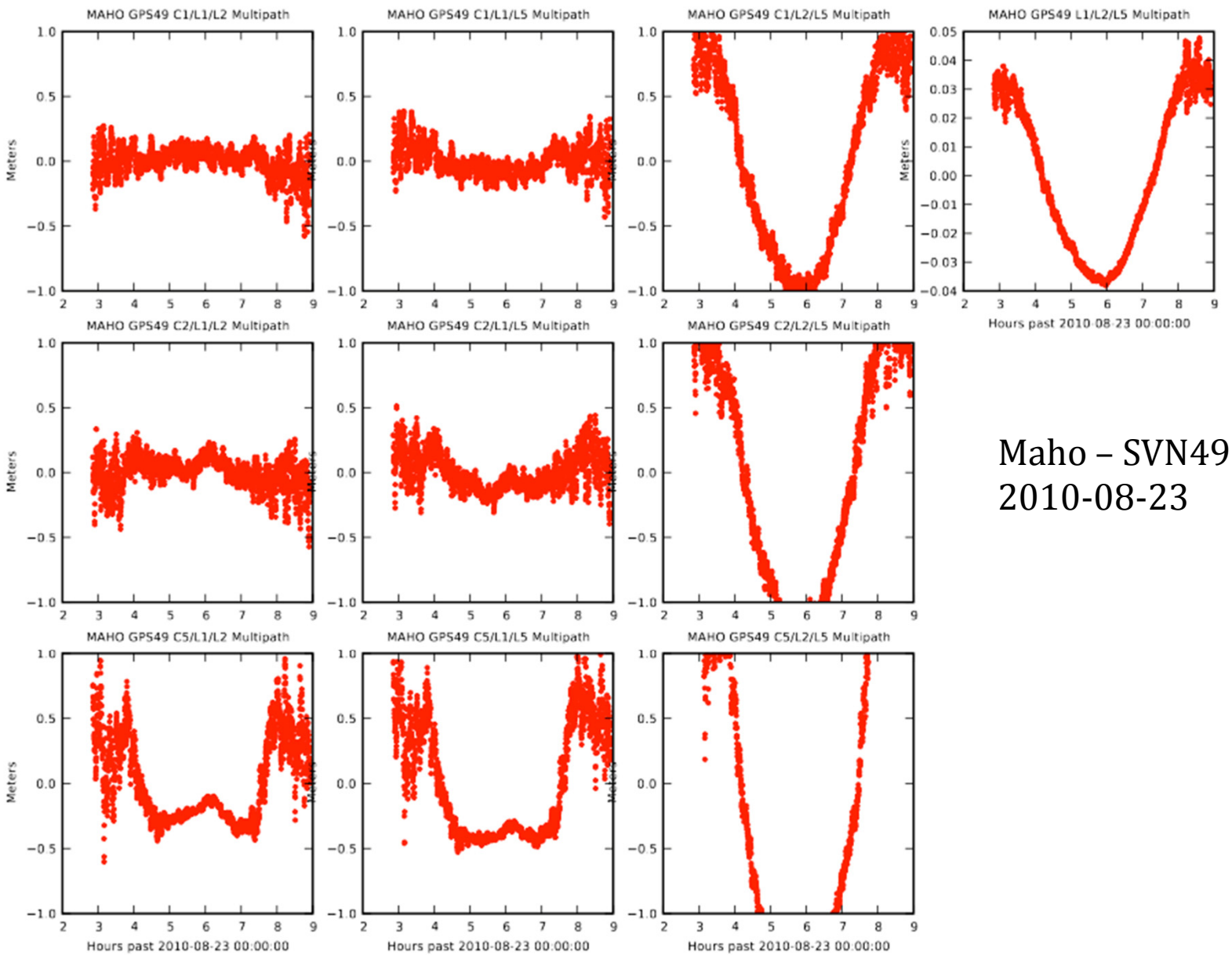





Karr – SVN49
2010-07-11




Wtzx – SVN49
2010-08-23



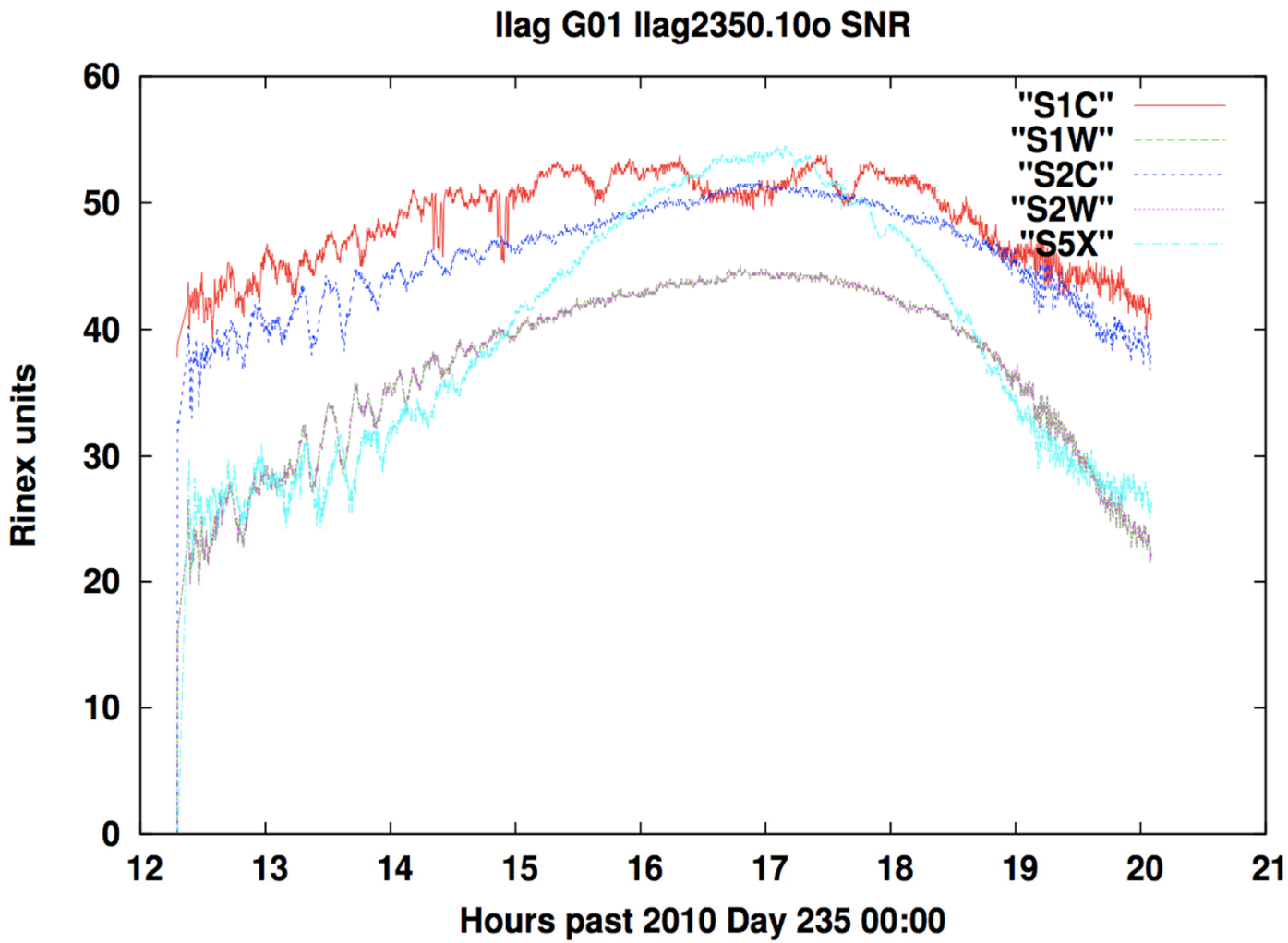

Maho – SVN49
2010-08-23

# SVN 49 nadir angle signature

- SVN 49 TCMP is most likely due to L5
- Dominated by nadir angle effect, (like L1 and L2 pseudorange issues?) not temperature
- L5 antenna power pattern is quite different from L1 and L2
- L5 pseudorange has nadir angle signature, larger than L1 or L2 pseudoranges

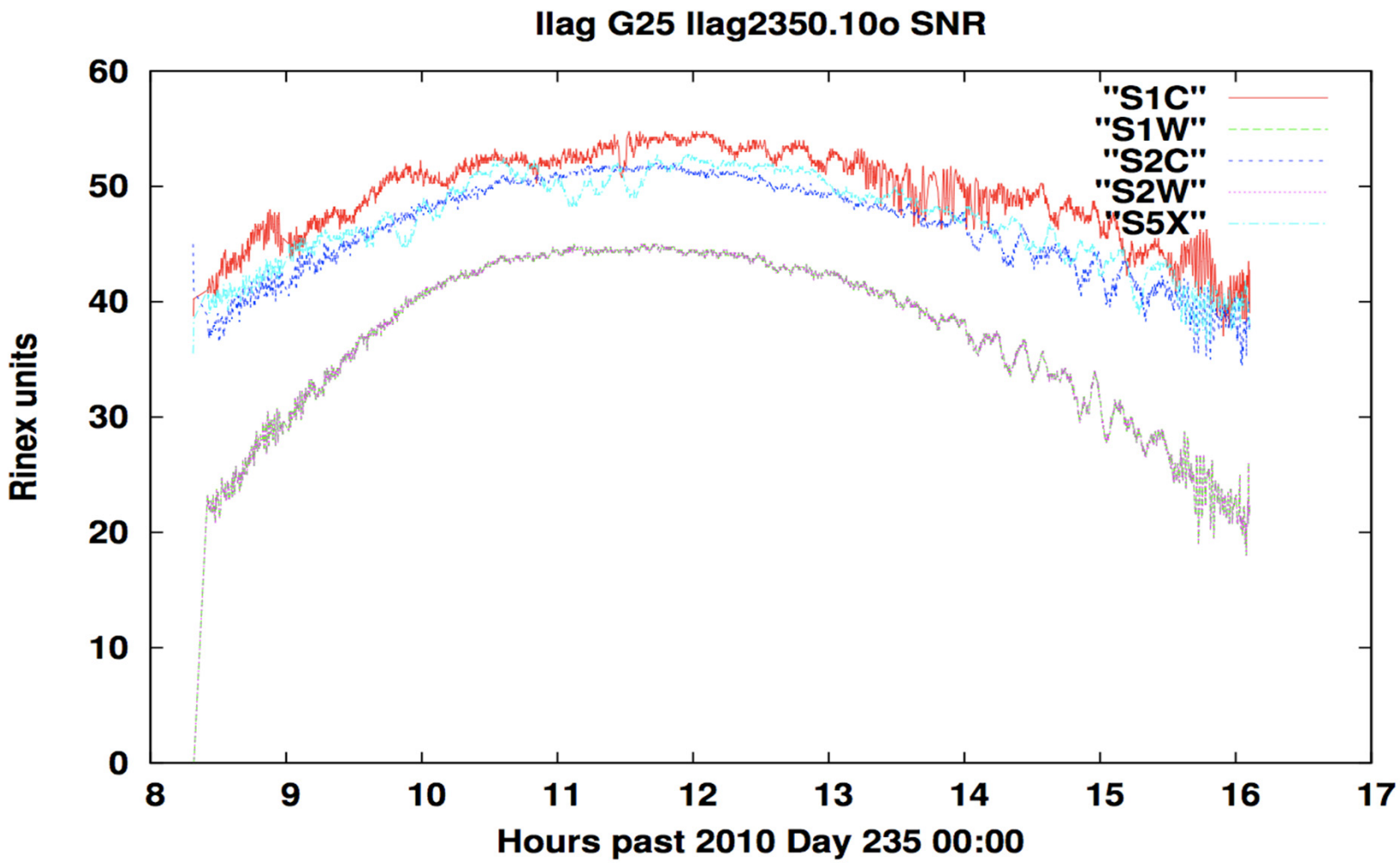
# SVN 49 SNR signature

- SVN 49 L5 elevation signature is different from L1 and L2



# SVN 62 SNR signature

- SVN 62 looks as expected



# Conclusions

- SVN 62 is the first Block IIF satellite
- SVN 62 has a strong semi-diurnal signature in its tri-carrier multipath combination. The most likely theory for the cause is a temperature-dependent hardware bias between the L5 and L1&L2 hardware.
- Must account for this in 3 frequency applications
- SVN 62 will have different dual-frequency clocks depending on whether one uses L1/L2 or L1/L5
- SVN 49, of course, has well-known onboard multipath problems with P1 and P2, and we see it has phase problems with L5 as well.

# Who Cares? (and not) about SVN 62 type phase variations?

- L5 carrier phase is not coherent with L1 and L2 phases but same for all directions for SVN62, varies with angle for SVN49
- This is a problem for
  1. Stand Alone Trilaning (navigation within lanes on highway)
  2. Data editor programs that rely on coherent carriers
  3. Ionospheric science
  4. Estimate different clock for L1, L5 than for L1, L2, ISC not frequent enough to capture ~20 cm cycle over 12 hours
  5. …
- This is not a problem for
  1. Stand alone users who only use phase to smooth pseudorange over few hundred seconds
  2. High accuracy network users who form differenced observables (SVN 62 problem cancels, but note SVN 49 carrier variation does NOT cancel)
  3. …

```
grommit 530: grep REC *.10o | sort -k2,4
chof2350.10o:Delta_00016         JAVAD TRE_G2T DELTA 3.1.6b1            REC # / TYPE / VERS
hrag2350.10o:Delta_00013         JAVAD TRE_G2T DELTA 3.1.6b1            REC # / TYPE / VERS
llag2350.10o:Delta_00017         JAVAD TRE_G2T DELTA 3.1.6              REC # / TYPE / VERS
sing2350.10o:Delta_00013         JAVAD TRE_G2T DELTA 3.1.6b1            REC # / TYPE / VERS
unbd2350.10o:Delta_00014         JAVAD TRE_G2T DELTA 3.1.6              REC # / TYPE / VERS
maho2350.10o:Delta_00143         JAVAD TRE_G3TH DELTA 3.1.6b1           REC # / TYPE / VERS
stfu2350.10o:Delta_00184         JAVAD TRE_G3TH DELTA 3.1.6b1           REC # / TYPE / VERS
unsx2350.10o:Delta_00183         JAVAD TRE_G3TH DELTA 3.1.6b1           REC # / TYPE / VERS
wtzx2350.10o:Delta_00049         JAVAD TRE_G3TH DELTA 3.1.6b1           REC # / TYPE / VERS
ohix2350.10o:495078              LEICA GRX1200+GNSS  7.54/4.010.S8      REC # / TYPE / VERS
roth2350.10o:495029              LEICA GRX1200+GNSS  8.00/4.005         REC # / TYPE / VERS
str22350.10o:4650K03463          TRIMBLE NETR5       3.84               REC # / TYPE / VERS
tid12350.10o:4843K33421          TRIMBLE NETR8       3.80               REC # / TYPE / VERS
karr2350.10o:4843K33396          TRIMBLE NETR8       4.03               REC # / TYPE / VERS
l5dt2350.10o:4906K34365          TRIMBLE NETR8       4.14               REC # / TYPE / VERS


grommit 531: grep "ANT " *.10o | sort -k2,4
tid12350.10o:205                 AOAD/M_T        JPLA                   ANT # / TYPE
roth2350.10o:765734              LEIAR25         LEIT                   ANT # / TYPE
ohix2350.10o:                    LEIAR25.R3      LEIT                   ANT # / TYPE
hrag2350.10o:09310005            LEIAR25.R3      LEIT                   ANT # / TYPE
maho2350.10o:09330045            LEIAR25.R3      LEIT                   ANT # / TYPE
unsx2350.10o:09330039            LEIAR25.R3      LEIT                   ANT # / TYPE
wtzx2350.10o:10020020            LEIAR25.R3      LEIT                   ANT # / TYPE
sing2350.10o:09060237            LEIAX1203+GNSS  NONE                   ANT # / TYPE
str22350.10o:2170236             TPSCR3_GGD      CONE                   ANT # / TYPE
llag2350.10o:31050629            TRM55971.00     NONE                   ANT # / TYPE
unbd2350.10o:30217879            TRM55971.00     NONE                   ANT # / TYPE
chof2350.10o:31187001            TRM57971.00     NONE                   ANT # / TYPE
stfu2350.10o:30123268            TRM57971.00     NONE                   ANT # / TYPE
karr2350.10o:4938353444          TRM59800.00     NONE                   ANT # / TYPE
l5dt2350.10o:4846A60449          TRM59800.00     NONE                   ANT # / TYPE
```

## CURRENT BLOCK II/IIA/IIR/IIR-M SATELLITES

| LAUNCH ORDER | PRN | SVN | LAUNCH DATE | FREQ STD | PLANE | US SPACE COMMAND ** |
|---|---|---|---|---|---|---|
| *II-1 | | 14 | 14 FEB 1989 | | | 19802 |
| *II-2 | | 13 | 10 JUN 1989 | | | 20061 |
| *II-3 | | 16 | 18 AUG 1989 | | | 20185 |
| *II-4 | | 19 | 21 OCT 1989 | | | 20302 |
| *II-5 | | 17 | 11 DEC 1989 | | | 20361 |
| *II-6 | | 18 | 24 JAN 1990 | | | 20452 |
| *II-7 | | 20 | 26 MAR 1990 | | | 20533 |
| *II-8 | | 21 | 02 AUG 1990 | | | 20724 |
| *II-9 | | 15 | 01 OCT 1990 | | | 20830 |
| IIA-10 | 32 | 23 | 26 NOV 1990 | Rb | E5 | 20959 |
| IIA-11 | 24 | 24 | 04 JUL 1991 | Cs | D5 | 21552 |
| *IIA-12 | | 25 | 23 FEB 1992 | Rb | A5 | 21890 |
| *IIA-13 | | 28 | 10 APR 1992 | | | 21930 |
| IIA-14 | 26 | 26 | 07 JUL 1992 | Rb | F5 | 22014 |
| IIA-15 | 27 | 27 | 09 SEP 1992 | Cs | A4 | 22108 |
| *IIA-16 | | 32 | 22 NOV 1992 | | F6 | 22231 |
| *IIA-17 | | 29 | 18 DEC 1992 | | | 22275 |
| *IIA-18 | | 22 | 03 FEB 1993 | | | 22446 |
| *IIA-19 | | 31 | 30 MAR 1993 | | | 22581 |
| *IIA-20 | | 37 | 13 MAY 1993 | | | 22657 |
| IIA-21 | 09 | 39 | 26 JUN 1993 | Cs | A1 | 22700 |
| *IIA-22 | | 35 | 30 AUG 1993 | Rb | | 22779 |
| IIA-23 | 04 | 34 | 26 OCT 1993 | Rb | D4 | 22877 |
| IIA-24 | 06 | 36 | 10 MAR 1994 | Rb | C5 | 23027 |
| IIA-25 | 03 | 33 | 28 MAR 1996 | Cs | C2 | 23833 |
| IIA-26 | 10 | 40 | 16 JUL 1996 | Cs | E3 | 23953 |
| IIA-27 | 30 | 30 | 12 SEP 1996 | Cs | B2 | 24320 |
| IIA-28 | 08 | 38 | 06 NOV 1997 | Cs | A3 | 25030 |
| ***IIR-1 | | 42 | 17 JAN 1997 | | | |
| IIR-2 | 13 | 43 | 23 JUL 1997 | Rb | F3 | 24876 |
| IIR-3 | 11 | 46 | 07 OCT 1999 | Rb | D2 | 25933 |
| IIR-4 | 20 | 51 | 11 MAY 2000 | Rb | E1 | 26360 |
| IIR-5 | 28 | 44 | 16 JUL 2000 | Rb | B3 | 26407 |
| IIR-6 | 14 | 41 | 10 NOV 2000 | Rb | F1 | 26605 |
| IIR-7 | 18 | 54 | 30 JAN 2001 | Rb | E4 | 26690 |
| IIR-8 | 16 | 56 | 29 JAN 2003 | Rb | B1 | 27663 |
| IIR-9 | 21 | 45 | 31 MAR 2003 | Rb | D3 | 27704 |
| IIR-10 | 22 | 47 | 21 DEC 2003 | Rb | E2 | 28129 |
| IIR-11 | 19 | 59 | 20 MAR 2004 | Rb | C3 | 28190 |
| IIR-12 | 23 | 60 | 23 JUN 2004 | Rb | F4 | 28361 |
| IIR-13 | 02 | 61 | 06 NOV 2004 | Rb | D1 | 28474 |
| IIR-14M | 17 | 53 | 26 SEP 2005 | Rb | C4 | 28874 |
| IIR-15M | 31 | 52 | 25 SEP 2006 | Rb | A2 | 29486 |
| IIR-16M | 12 | 58 | 17 NOV 2006 | Rb | B4 | 29601 |
| IIR-17M | 15 | 55 | 17 OCT 2007 | Rb | F2 | 32260 |
| IIR-18M | 29 | 57 | 20 DEC 2007 | Rb | C1 | 32384 |
| IIR-19M | 07 | 48 | 15 MAR 2008 | Rb | A6 | 32711 |
| IIR-20M | 01 | 49 | 24 MAR 2009 | Rb | B6 | 34661 |
| IIR-21M | 05 | 50 | 17 AUG 2009 | Rb | E6 | 35752 |
| IIF-1 | 25 | 62 | 28 MAY 2010 | Rb | B2 | 36585 |