International Symposium on GNSS 2015 Kyoto

17B1-12

QZSS-1 Precise Orbit Determination by MADOCA

Tomoji TAKASU
LHTC/Tokyo University of Marine Science and Technology
Motoyuki MIYOSHI, Kaori KAWATE, Satoshi KOGURE
JAXA

November 16-18, 2015@Miyakomesse, Kyoto

Contents

- MADOCA and QZSS-1 Overview
- QZSS-1 Orbit Determination
- QZSS-1 Orbit Evaluation
- Summary

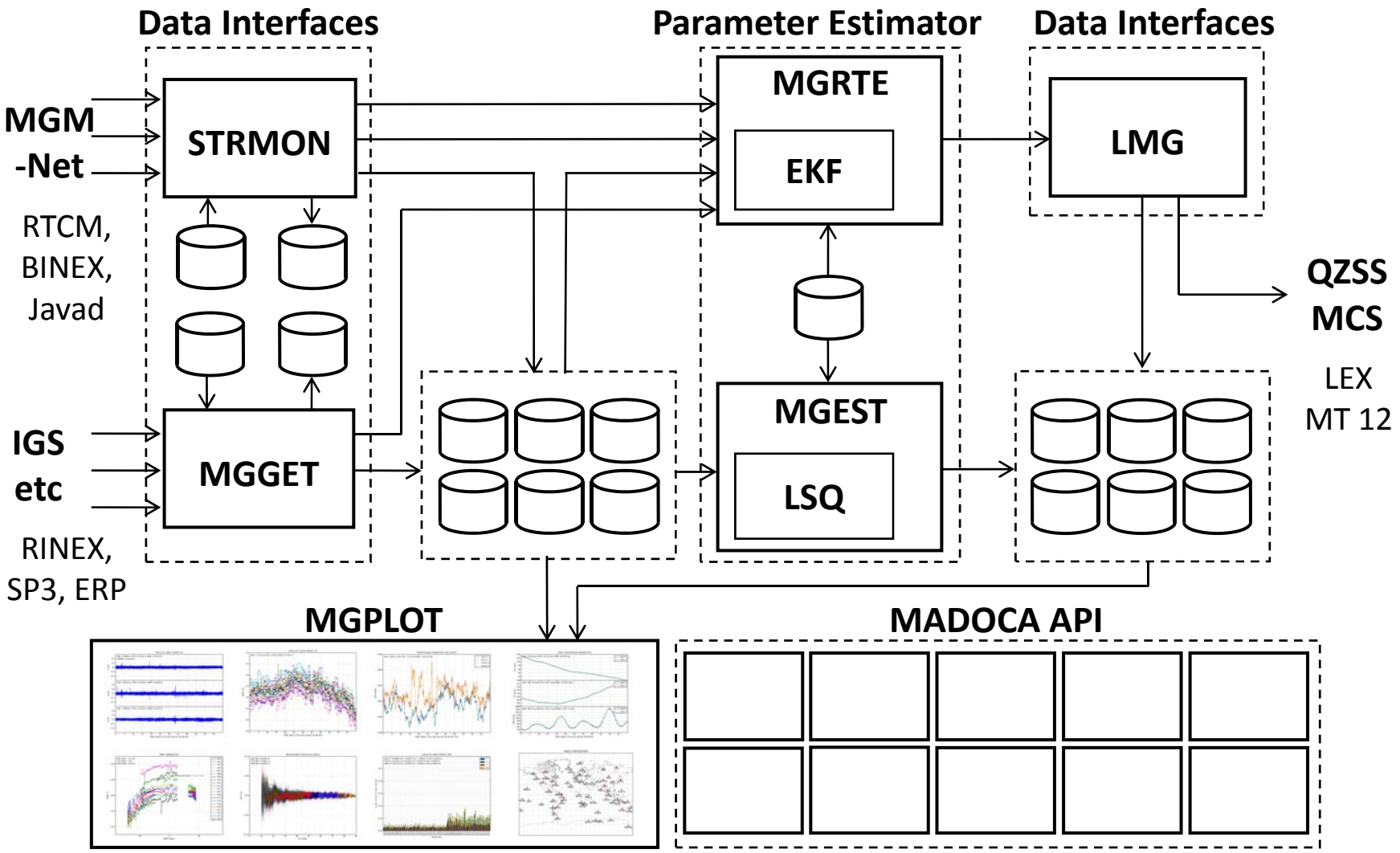
MADOCA and QZSS-1 Overview

MADOCA

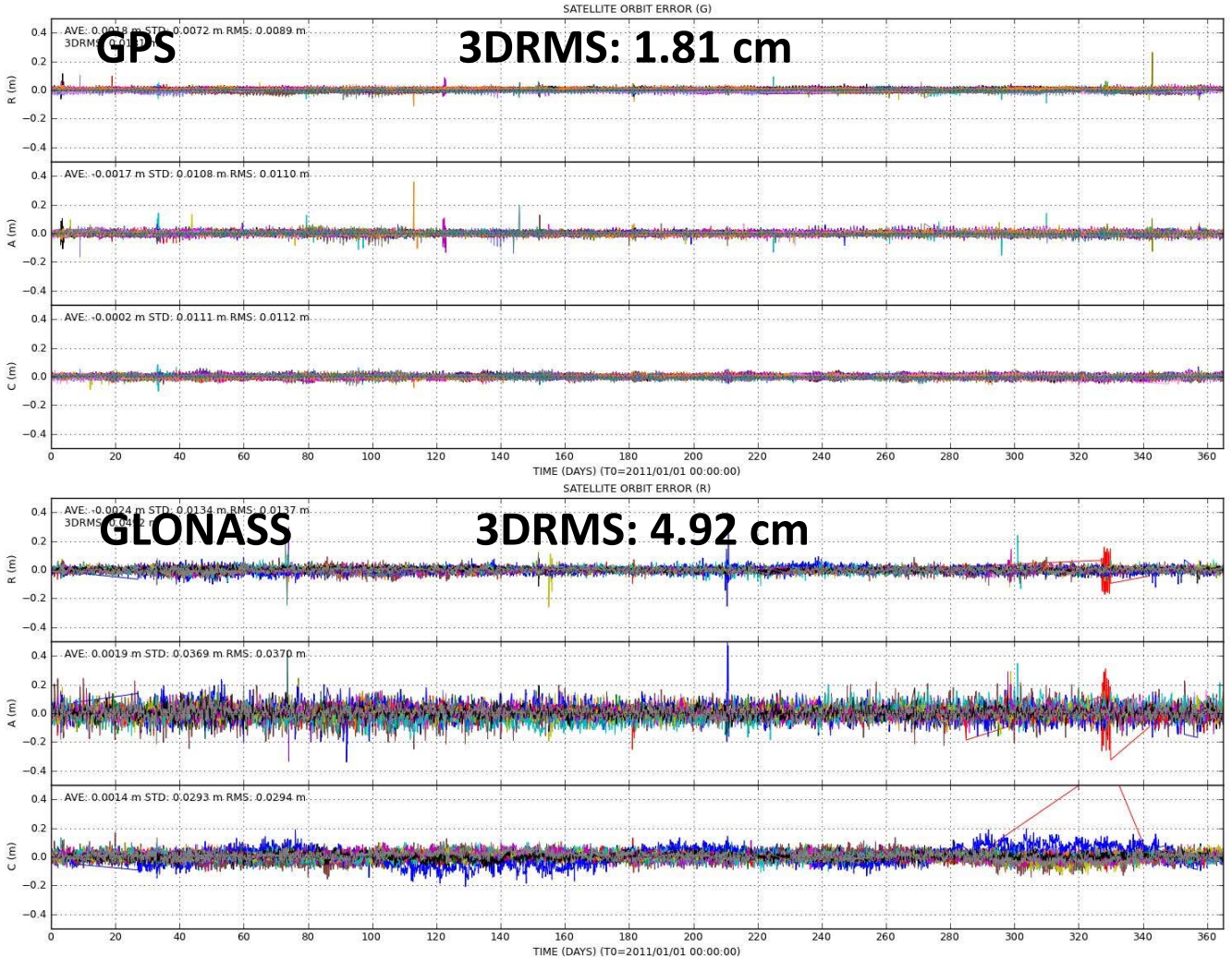
Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis

- **Developed by JAXA from scratch (2011/6~)**
- **Originally for real-time PPP service via QZSS LEX**
  Many (potential) applications over global area
- **Satellite orbit and clock determination for multi-GNSS constellation**
  GPS, GLONASS, QZSS, Galileo and BeiDou
- **Both of batch and real-time processing**

MADOCA Architecture



GPS/GLO Orbit Accuracy

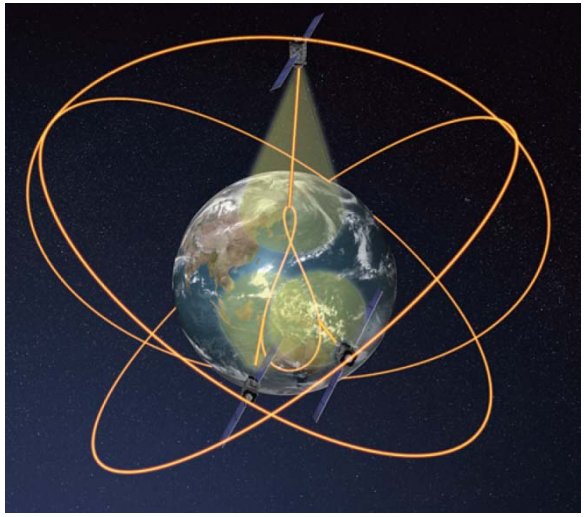


	RMS
Radial	0.89 cm
Along-Track	1.10 cm
Cross-Track	1.12 cm
Radial	1.37 cm
Along-Track	3.70 cm
Cross-Track	2.94 cm

2011/1/1 - 12/31 (365 days), by MADOCA 0.3.0, wrt IGS Final

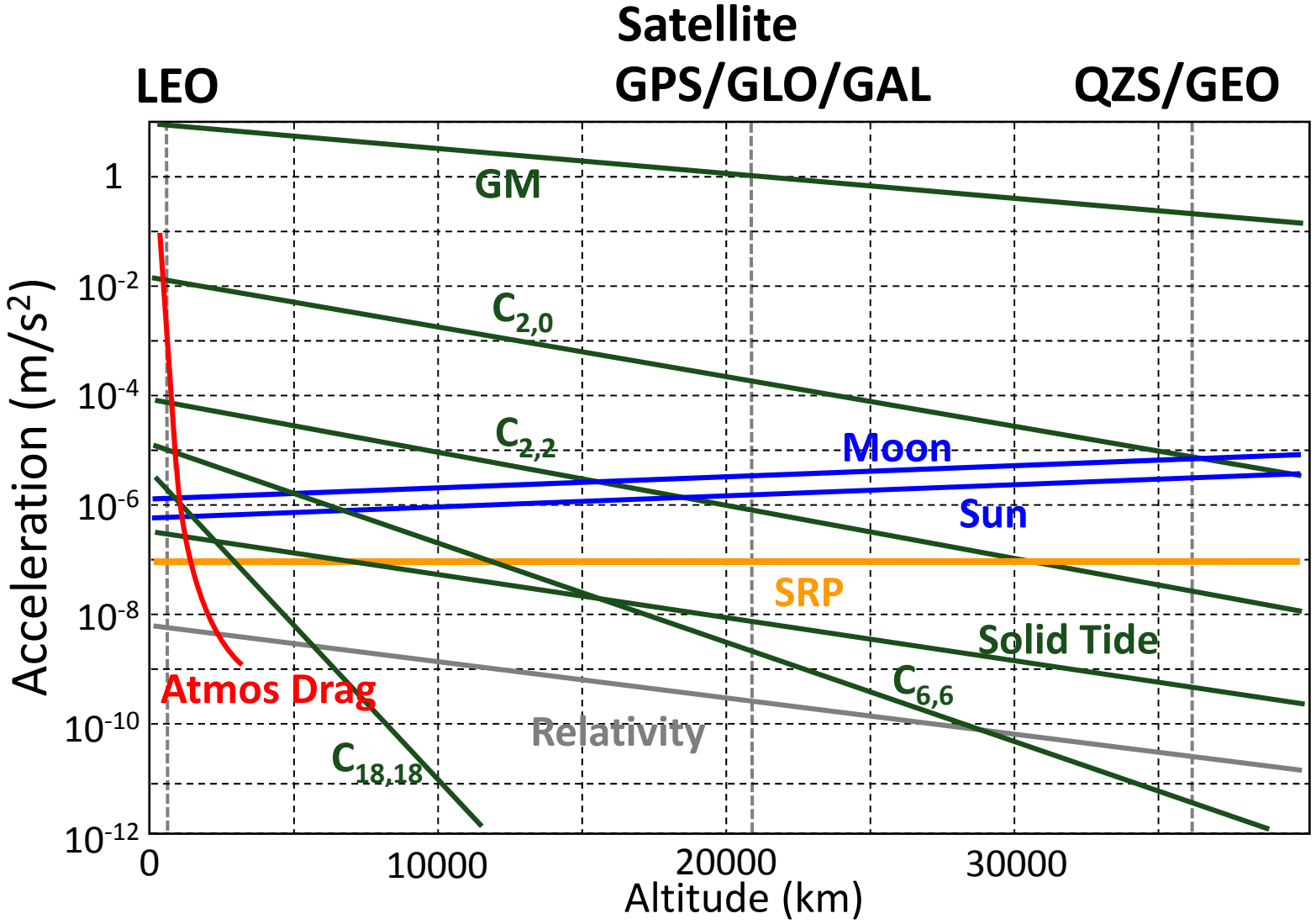
QZSS-1 "Michibiki"

- **The first Regional Navigation Satellite in Japan**
- **Launch:**
  September 11, 2010 by H2A-18
- **Orbit: IGSO**
  (A=42164 km, e=0.075, i=43 deg, omega=270 deg)
- **Navigation Signals:**
  L1C/A, L1C, L1-SAIF, L2C, L5, LEX
- **Developed and operated by JAXA**



QZSS-1 Orbit Determination

Force Models (1/2)



Force Models (2/2)

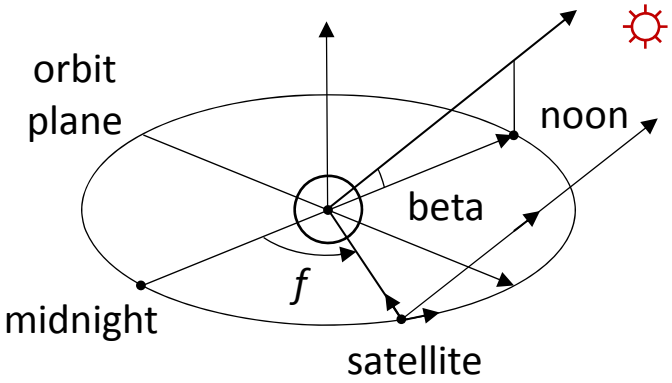
$$\boldsymbol{a}(t,\boldsymbol{r},\boldsymbol{v},\boldsymbol{p}) = \boldsymbol{a}_{geop} + \boldsymbol{a}_{body} + \boldsymbol{a}_{srp} + \boldsymbol{a}_{drag} + \boldsymbol{a}_{emp} + \boldsymbol{a}_{thru} + \boldsymbol{a}_{rel}$$

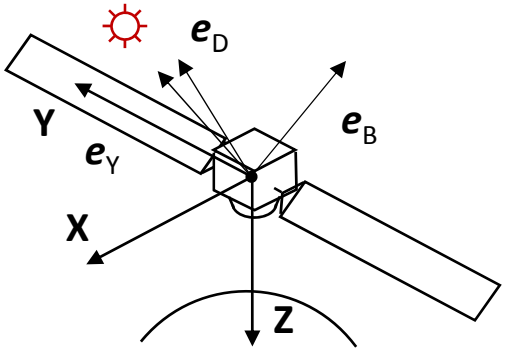
- **Geopotential**
  - EGM96 or EGM2008 up to 150 order/degree
  - Rate, solid earth tide, pole tide corrections by IERS 2010
  - Ocean tide corrections by IERS 2010 and FES2004
- **Third-Body Potentials**
  - Moon, Sun, Jupiter and Venus (point of mass)
  - Planetary ephemeris by JPL DE405/421
- **SRP, Atmospheric Drag, Empirical Accel., Thruster Accel. and General Relativity**

Parameter Adjustment

	Batch	Real-Time
Algorithm	Iterated Weighted LSQ	Dual-Cycle-EKF
Estimated Parameters	Orbit, SRP, Drag, Emp-Acc, Thru-Acc, Sat/Rcv Clock, Position, ZTD/Grad, Amb, EOP, Geocenter, Rcv Bias	
Measurements	ZD (zero-diff.) Carrier-Phase and Peudorange	
Numerical Solver	NEQ by Cholesky Factorization	Numerical Stable EKF
Clock Estimation	Parameter Elimination in NEQ	State as White-Noise or Random-Walk
Integer Ambiguity Resolution	Network AR (Ge., 2005)	Real-Time Network AR

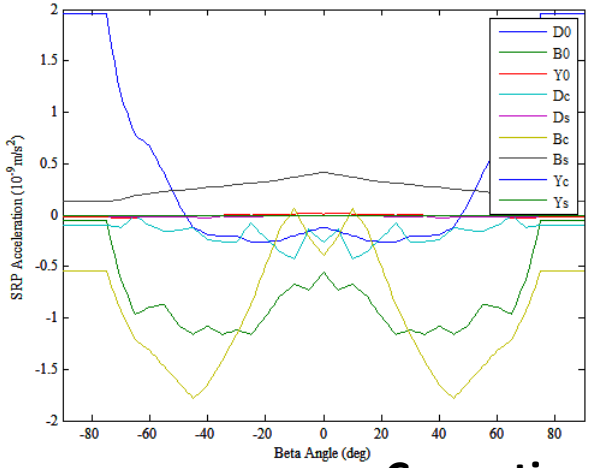
MDBY SRP Model (~ver.0.6.7)



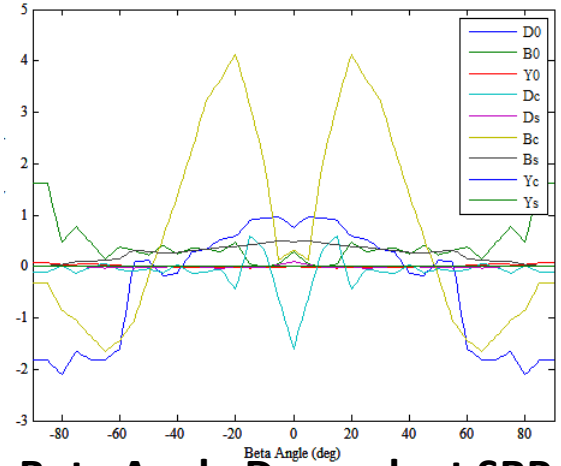


$$a_{srp} = S\,((D_0 + D_C \cos f + D_S \sin f)\, e_D + (B_0 + B_C \cos f + B_S \sin f)\, e_B + (Y_0 + Y_C \cos f + Y_S \sin f)\, e_Y) * 10^{-9}\ (m/s^2)$$

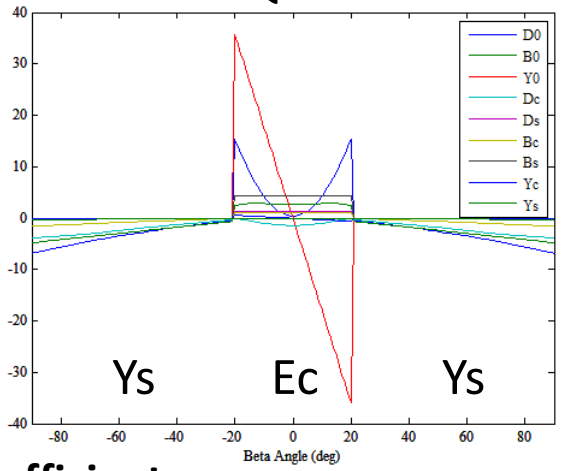
GPS Block IIR



GLONASS

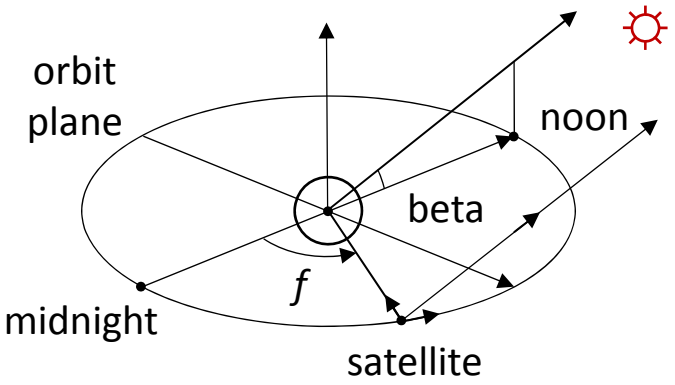


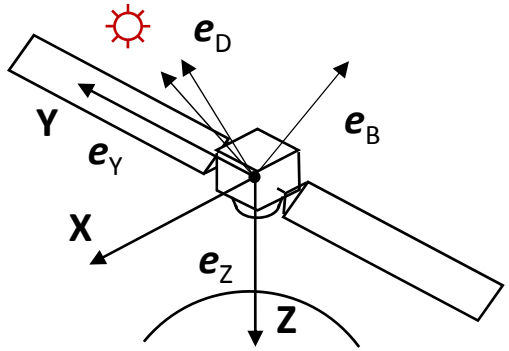
QZSS



Correction by Beta Angle Dependent SRP Coefficients

EDBY SRP Model (ver. 0.7.0~)





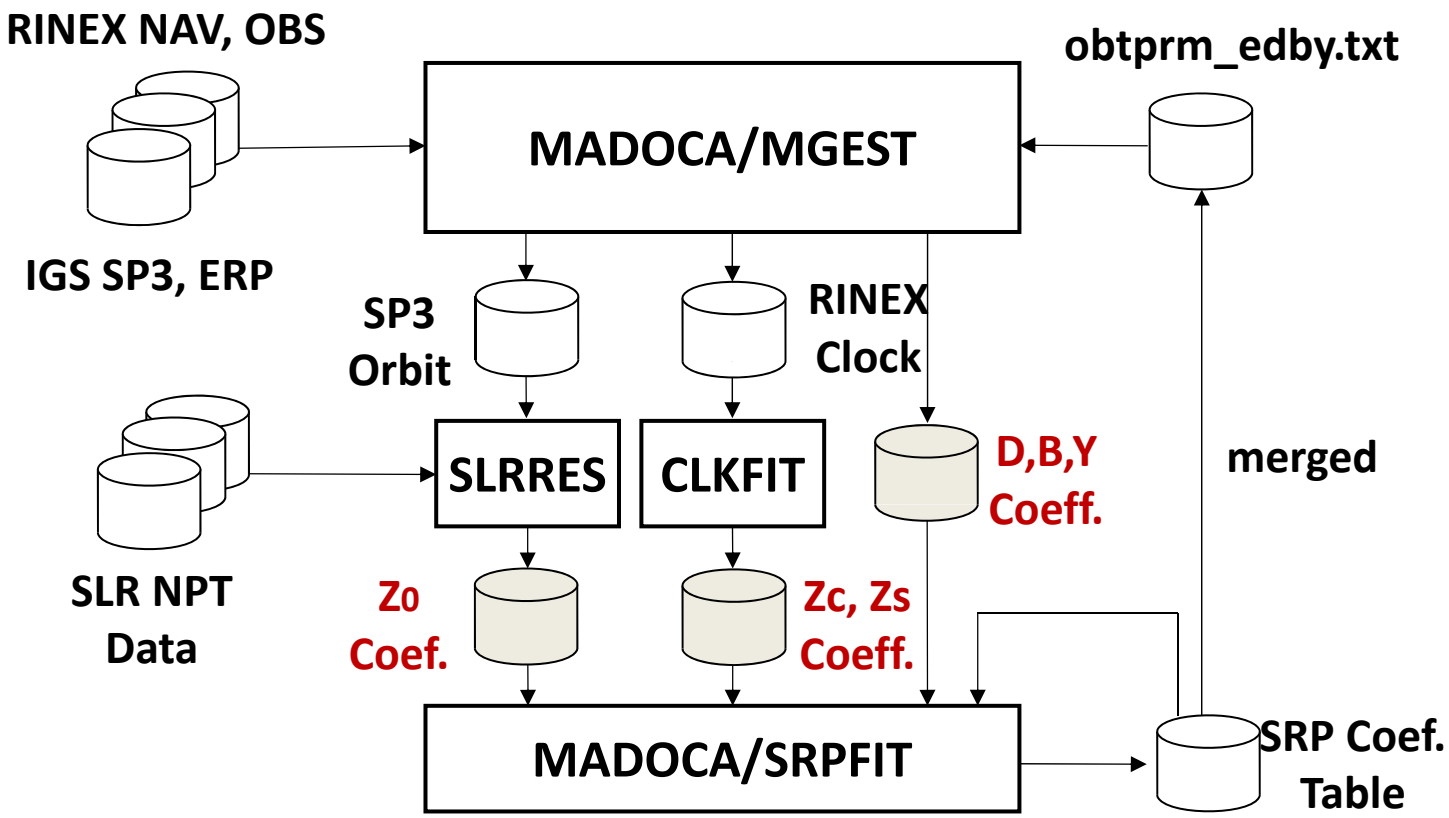
YS: $a_{srp} = S\,((D_0 + D_C \cos f + D_S \sin f)\, e_D +$
$(B_0 + B_C \cos f + B_S \sin f)\, e_B +$
$(Y_0 + Y_C \cos f + Y_S \sin f)\, e_Y +$
$(Z_0 + Z_C \cos f + Z_S \sin f)\, e_z) * 10^{-9}\ (m/s^2)$

EC: $a_{srp} = S\,((D_0 + D_C \cos f + D_S \sin f +$
$D_{2C} \cos 2f + D_{2S} \sin 2f)\, e_D + B_0\, e_B +$
$(Y_0 + Y_C \cos f + Y_S \sin f)\, e_Y +$
$(Z_0 + Z_C \cos f + Z_S \sin f)\, e_z) * 10^{-9}\ (m/s^2)$

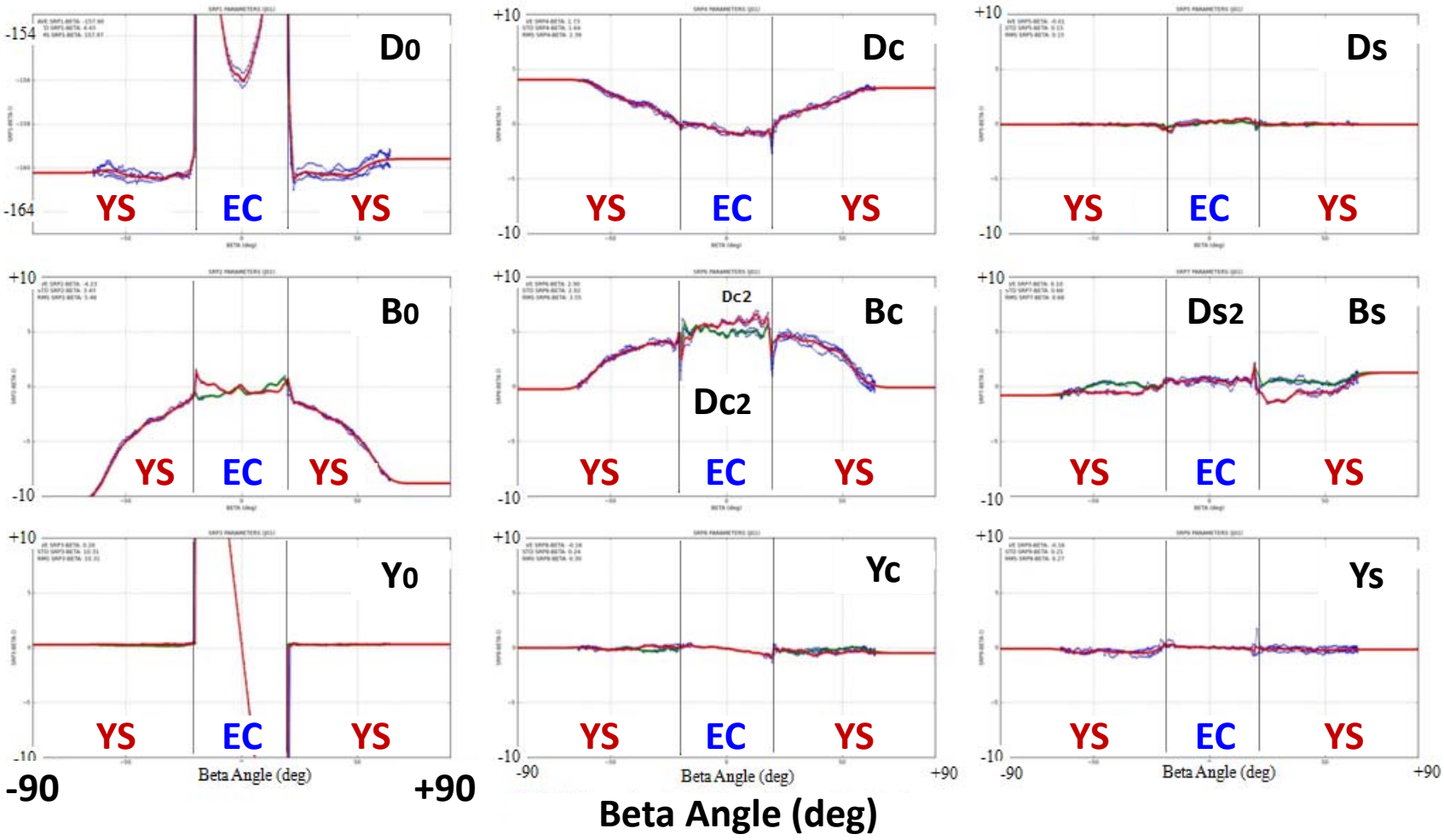
$(S = F_{Shadow} * AU^2 / |r - r_{sun}|^2)$

Determination of SRP Coeff.

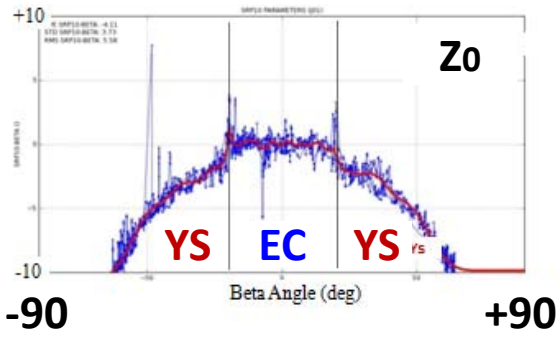
- With 23 month (2013/1 - 2014/11) MGEX/SLR Data
- Several Iterations by AWS Environment

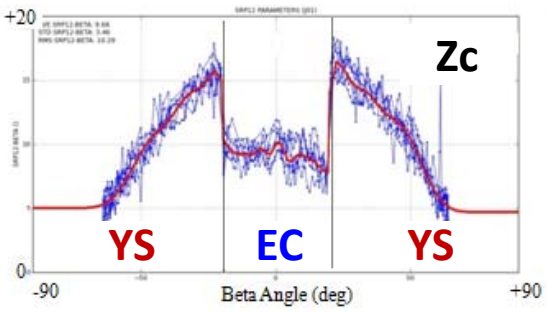


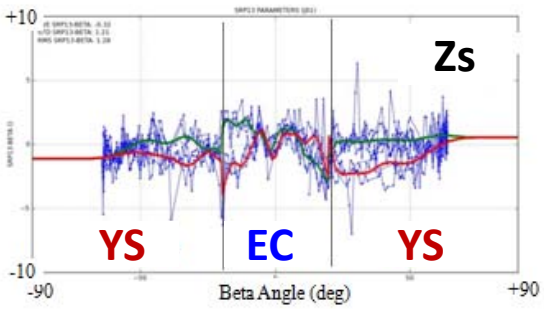
EDBY SRP Coefficients (1/2)



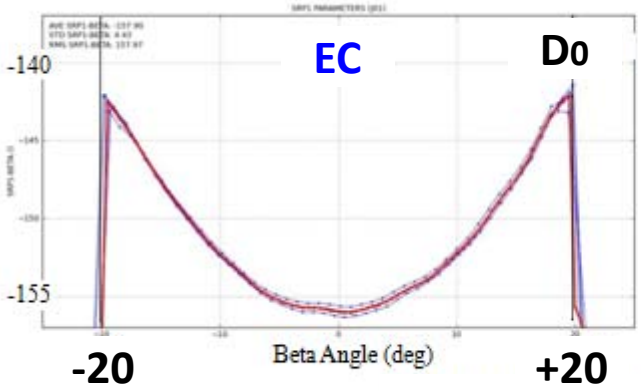
EDBY SRP Coefficients (2/2)

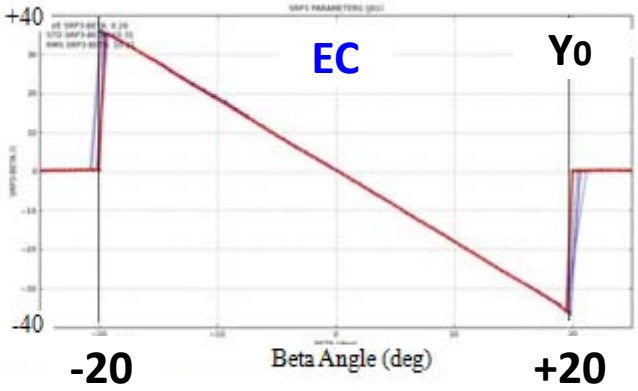






Beta Angle (deg)





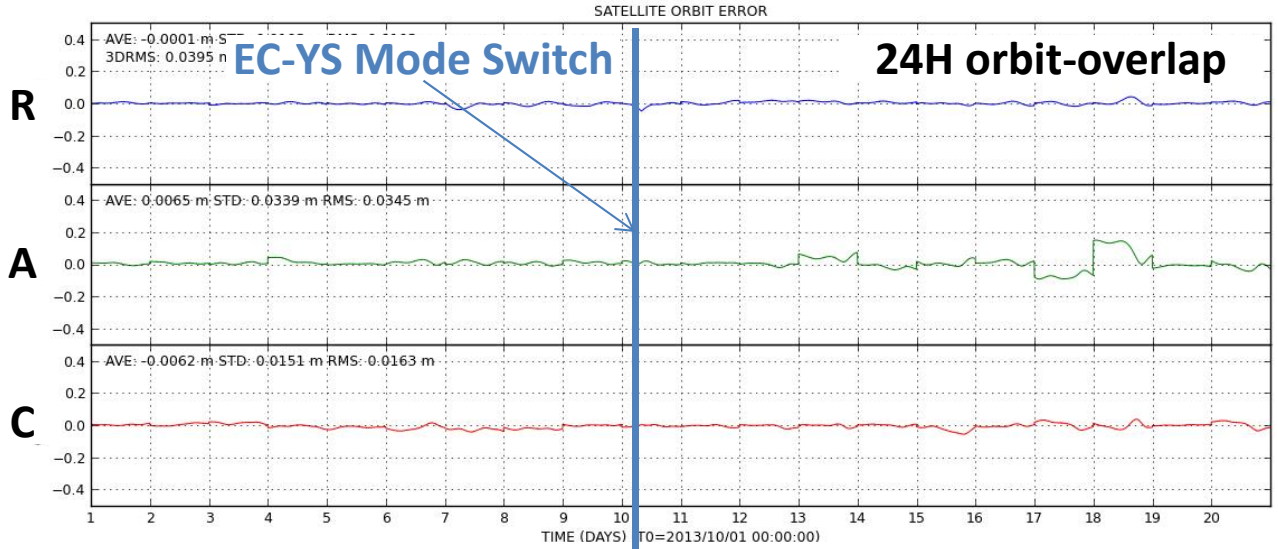
Beta Angle (deg)

EDBY SRP Coefficients Table

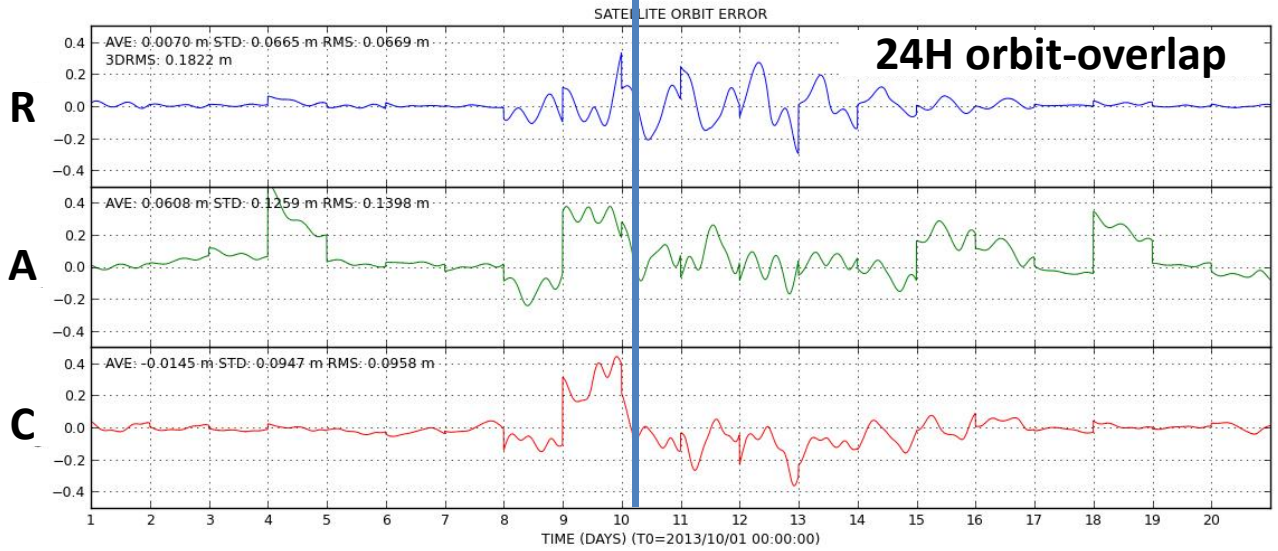
```
#
# ORBIT PARAMETERS FOR EDBY SRP MODEL
#
# history : 2014/07/22  1.0  new
#           2014/12/11  1.1  E18, C01-C14,C30 added
#           2014/12/28  2.0  update D0,B0,Y0,Dc,Ds,Bc,Bs,Yc,Ys and add Z0,Zc,Zs for QZSS
#+SRP PARAMETERS
#SAT     OPR START(GPST)  T E H   BETA     SRP-1   SRP-2   SRP-3   SRP-4   SRP-5   SRP-6   SRP-7   SRP-8   SRP-9
J01  2010/11/29 00:00:00 12 0 0   0.00 -149.357   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000  # SAT MASS: 2292.059 kg
J01  2011/05/11 00:00:00 12 0 0   0.00 -149.763   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000  # SAT MASS: 2285.869 kg
J01  2011/11/09 00:00:00 12 0 0   0.00 -150.077   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000  # SAT MASS: 2281.080 kg
J01  2012/05/02 00:00:00 12 0 0   0.00 -150.343   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000  # SAT MASS: 2277.039 kg
J01  2012/11/07 00:00:00 12 0 0   0.00 -150.564   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000  # SAT MASS: 2273.696 kg
J01  2013/05/01 00:00:00 12 0 0   0.00 -150.756   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000  # SAT MASS: 2270.814 kg
J01  2013/10/30 00:00:00 12 0 0   0.00 -150.895   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000  # SAT MASS: 2268.723 kg
J01  2014/04/30 00:00:00 12 0 0   0.00 -151.006   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000  # SAT MASS: 2267.047 kg
#-SRP PARAMETERS
#+SRP BETA COEFFICIENTS
# typ ind flg int c1 c2 c3 ...
#   typ : satellite type  (2:GPSIIA,3:GPSIIR,4:GPSIIRM,5:GPSIIF,6:GPSIIIA,9:GLOM,11:GAL,12:QZS,13:QZS-G,14:QZS-Q)
#   ind : parameter index (1:D0,2:B0,3:Y0,4:Dc,5:Ds,6:Bc/Dc2,7:Bs/Ds2,8:Yc,9:Ys,10:Z0,11:X0,12:Zc,13:Zs,14:Zc2,15:Zs2)
#   flg : beta angle flag (0:all,1:beta>=0&rate>=0,2:beta>=0&rate<0,3:beta<0&rate<0,4:beta<0&rate>=0,5-8:QZSS-Ec)
#   int : beta angle interval (deg)
#   cd  : accel correction at beta angle # d (10^-9m/s^2)
# D0,B0,Y0,Dc,Ds,Bc,Bs,Yc,Ys COEFFICIENTS by SRPFIT 0.2.0
#T  P F INT     0.0    2.5    5.0    7.5   10.0   12.5   15.0   17.5   20.0   22.5   25.0   27.5   30.0   32.5   35.0   37.5   40.0   42.5   45.0   47.5   50.0   52.5   55.0   57.5   60.0   62.5   65.0   67.5   70.0   72.5   75.0   77.5   80.0   82.5   85.0   87.5   90.0
12  1 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -4.87  -9.71  -9.47  -9.38  -9.42  -9.44  -9.52  -9.52  -9.46  -9.49  -9.54  -9.50  -9.37  -9.19  -9.04  -8.93  -8.86  -8.82  -8.80  -8.79  -8.78  -8.78  -8.78  -8.78  -8.78  -8.78  -8.78  -8.78  -8.78
12  1 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -8.38  -9.43  -9.58  -9.47  -9.57  -9.66  -9.65  -9.64  -9.62  -9.59  -9.59  -9.59  -9.52  -9.41  -9.33  -9.30  -9.32  -9.36  -9.40  -9.41  -9.42  -9.42  -9.42  -9.42  -9.42  -9.42  -9.42  -9.42
12  2 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.71  -1.37  -1.51  -1.75  -1.92  -2.12  -2.55  -2.90  -3.03  -3.25  -3.70  -4.20  -4.67  -5.21  -5.92  -6.75  -7.53  -8.14  -8.53  -8.73  -8.80  -8.82  -8.82  -8.82  -8.82  -8.82  -8.82  -8.82  -8.82
12  2 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.61  -1.25  -1.59  -1.86  -2.17  -2.59  -2.92  -3.03  -3.19  -3.61  -4.14  -4.57  -4.99  -5.61  -6.55  -7.65  -8.68  -9.47  -9.97 -10.22 -10.32 -10.34 -10.34 -10.34 -10.34 -10.34 -10.34 -10.34 -10.34
12  3 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.02   0.34   0.31   0.27   0.28   0.28   0.27   0.27   0.28   0.30   0.31   0.32   0.31   0.30   0.30   0.31   0.31   0.32   0.32   0.32   0.32   0.32   0.32   0.32   0.32   0.32   0.32   0.32
12  3 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.47   0.35   0.29   0.30   0.33   0.33   0.31   0.31   0.31   0.30   0.29   0.27   0.28   0.29   0.30   0.30   0.30   0.30   0.29   0.29   0.29   0.29   0.29   0.29   0.29   0.29   0.29   0.29
12  3 3 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.31   0.31   0.25   0.29   0.29   0.25   0.25   0.27   0.26   0.25   0.25   0.26   0.27   0.27   0.27   0.28   0.29   0.30   0.31   0.32   0.32   0.32   0.32   0.32   0.32   0.32   0.32   0.32
12  3 4 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.38   0.33   0.20   0.16   0.18   0.17   0.16   0.18   0.19   0.21   0.21   0.21   0.21   0.22   0.23   0.25   0.26   0.27   0.28   0.28   0.28   0.29   0.29   0.29   0.29   0.29   0.29   0.29
12  4 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.28   0.27   0.71   0.83   0.95   1.20   1.41   1.54   1.65   1.77   1.93   2.13   2.39   2.65   2.88   3.05   3.17   3.23   3.27   3.29   3.30   3.30   3.30   3.30   3.30   3.30   3.30   3.30
12  4 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.17   0.36   0.75   0.92   1.22   1.67   1.82   1.74   1.83   2.11   2.35   2.51   2.72   3.01   3.34   3.63   3.83   3.95   4.02   4.05   4.06   4.06   4.06   4.06   4.06   4.06   4.06   4.06
12  5 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.19  -0.12   0.03  -0.06  -0.03   0.04  -0.02  -0.08  -0.02   0.06   0.07   0.04   0.01  -0.00  -0.01  -0.02  -0.03  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04
12  5 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.57  -0.15  -0.02  -0.04  -0.05  -0.03  -0.02  -0.03  -0.03  -0.02  -0.02  -0.04  -0.05  -0.06  -0.06  -0.05  -0.04  -0.03  -0.03  -0.03  -0.03  -0.02  -0.02  -0.02  -0.02  -0.02  -0.02  -0.02
12  5 3 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.50   0.15  -0.13  -0.12  -0.07  -0.11  -0.09  -0.02  -0.02  -0.06  -0.06  -0.05  -0.03  -0.02  -0.01  -0.01  -0.01  -0.02  -0.03  -0.03  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04  -0.04
12  5 4 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.10  -0.09  -0.12  -0.12  -0.04  -0.06  -0.14  -0.14  -0.09  -0.07  -0.06  -0.04  -0.02   0.00   0.00  -0.00  -0.01  -0.02  -0.02  -0.02  -0.02  -0.02  -0.02  -0.02  -0.02  -0.02  -0.02
12  6 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   4.00   4.52   4.59   4.63   4.50   4.22   4.19   4.16   3.85   3.52   3.39   3.29   2.96   2.35   1.64   0.99   0.51   0.21   0.03  -0.05  -0.08  -0.09  -0.09  -0.09  -0.09  -0.09  -0.09  -0.09
12  6 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   4.90   3.70   4.08   4.06   3.98   3.98   3.77   3.51   3.44   3.35   3.10   2.80   2.54   2.26   1.83   1.27   0.72   0.27  -0.02  -0.17  -0.22  -0.24  -0.24  -0.24  -0.24  -0.24  -0.24  -0.24
12  7 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.20  -0.59  -1.43  -1.37  -1.26  -1.35  -0.97  -0.47  -0.43  -0.61  -0.62  -0.53  -0.53  -0.55  -0.42  -0.10   0.32   0.70   0.98   1.14   1.22   1.25   1.26   1.26   1.26   1.26   1.26   1.26
12  7 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.21  -0.22  -0.05  -0.24  -0.67  -0.67  -0.55  -0.58  -0.57  -0.49  -0.50  -0.57  -0.58  -0.49  -0.41  -0.41  -0.48  -0.58  -0.68  -0.74  -0.78  -0.79  -0.80  -0.80  -0.80  -0.80  -0.80  -0.80
12  7 3 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.40   0.56   0.72   0.57   0.46   0.54   0.54   0.45   0.41   0.37   0.26   0.16   0.22   0.44   0.75   1.02   1.19   1.26   1.28   1.27   1.26   1.26   1.26   1.26   1.26   1.26
12  7 4 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.02  -0.02   0.05  -0.07   0.09   0.38   0.34   0.15   0.19   0.39   0.44   0.31   0.13  -0.05  -0.23  -0.43  -0.60  -0.73  -0.79  -0.81  -0.81  -0.80  -0.80  -0.80  -0.80  -0.80  -0.80  -0.80
12  8 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.29  -0.12  -0.27  -0.30  -0.24  -0.50  -0.74  -0.61  -0.41  -0.41  -0.50  -0.47  -0.35  -0.26  -0.27  -0.33  -0.41  -0.47  -0.49  -0.49  -0.48  -0.48  -0.48  -0.48  -0.48  -0.48  -0.48  -0.48
12  8 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.07   0.14   0.10   0.10   0.22   0.17  -0.00  -0.09  -0.11  -0.14  -0.19  -0.19  -0.14  -0.07  -0.02   0.01   0.02   0.02   0.02   0.01   0.01   0.01   0.01   0.01   0.01   0.01   0.01
12  8 3 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.30  -0.27  -0.34  -0.52  -0.46  -0.32  -0.26  -0.23  -0.19  -0.19  -0.18  -0.10   0.01   0.05  -0.01  -0.14  -0.27  -0.37  -0.43  -0.46  -0.48  -0.48  -0.48  -0.48  -0.48  -0.48  -0.48  -0.48
12  8 4 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -0.24   0.04  -0.18  -0.33  -0.30  -0.27  -0.20  -0.06   0.02  -0.04  -0.14  -0.19  -0.16  -0.11  -0.05  -0.02  -0.01   0.00   0.01   0.01   0.01   0.01   0.01   0.01   0.01   0.01   0.01
12  9 1 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.11  -0.12  -0.13  -0.05  -0.07  -0.13  -0.12  -0.09  -0.12  -0.18  -0.24  -0.25  -0.23  -0.20  -0.17  -0.16  -0.16  -0.16  -0.16  -0.17  -0.17  -0.17  -0.17  -0.17  -0.17  -0.17  -0.17  -0.17
12  9 2 2.5   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.12  -0.20  -0.40  -0.43  -0.48  -0.49  -0.42  -0.38  -0.42  -0.39  -0.28  -0.22  -0.29  -0.40  -0.45  -0.41  -0.31  -0.21  -0.14  -0.10  -0.08  -0.08  -0.08  -0.08  -0.08  -0.08  -0.08  -0.08
12  1 5 1.0  -5.18  -5.22  -5.05  -4.83  -4.55  -4.11  -3.68  -3.35  -2.88  -2.18  -1.45  -0.72   0.20   1.30   2.35   3.31   4.49   6.01   7.50   8.28   9.10
12  1 6 1.0  -5.18  -5.00  -4.94  -4.91  -4.73  -4.45  -4.10  -3.58  -2.88  -2.19  -1.51  -0.71   0.20   1.13   2.09   3.17   4.37   5.57   6.70   7.76   8.79
12  2 5 1.0   0.10  -0.14  -0.38  -0.53  -0.62  -0.61  -0.52  -0.51  -0.58  -0.57  -0.46  -0.38  -0.38  -0.41  -0.45  -0.48  -0.45  -0.25   0.10   0.43   0.54
12  2 6 1.0   0.10   0.12  -0.11  -0.37  -0.54  -0.63  -0.60  -0.46  -0.34  -0.26  -0.10   0.12   0.24   0.20   0.15   0.20   0.30   0.41   0.59   1.00   1.75
12  2 7 1.0  -0.27  -0.52  -0.68  -0.70  -0.64  -0.59  -0.60  -0.61  -0.55  -0.39  -0.18   0.05   0.23   0.26   0.15   0.10   0.28   0.60   0.78   0.55  -0.12
12  2 8 1.0  -0.27  -0.08  -0.06  -0.19  -0.36  -0.50  -0.55  -0.57  -0.67  -0.84  -0.93  -0.90  -0.84  -0.84  -0.86  -0.88  -0.94  -1.07  -1.16  -0.97  -0.37
12  3 5 1.0   0.39  -1.39  -3.22  -5.07  -6.87  -8.70 -10.60 -12.48 -14.27 -16.04 -17.88 -19.78 -21.64 -23.48 -25.33 -27.14 -28.89 -30.61 -32.48 -34.62 -37.03
12  3 6 1.0   0.39   2.15   3.90   5.66   7.44   9.28  11.17  13.08  15.00  16.87  18.65  20.37  22.15  24.05  25.99  27.87  29.66  31.40  33.13  34.81  36.37
12  4 5 1.0  -0.83  -0.86  -0.76  -0.77  -0.88  -0.93  -0.96  -0.97  -0.82  -0.63  -0.67  -0.86  -0.87  -0.74  -0.76  -0.95  -0.97  -0.70  -0.57  -1.00  -1.50
12  4 6 1.0  -0.83  -0.68  -0.67  -0.70  -0.52  -0.27  -0.27  -0.38  -0.32  -0.16  -0.08  -0.09  -0.09  -0.07  -0.07  -0.07  -0.04   0.01   0.00  -0.14  -0.45
12  5 5 1.0   0.25   0.26   0.21   0.21   0.27   0.32   0.33   0.33   0.30   0.26   0.28   0.37   0.44   0.43   0.41   0.44   0.49   0.48   0.35   0.16   0.01
12  5 6 1.0   0.25   0.21   0.17   0.15   0.16   0.22   0.23   0.15   0.06   0.04   0.01  -0.03  -0.03   0.02  -0.02  -0.24  -0.55  -0.73  -0.65  -0.34   0.04
12  5 7 1.0   0.19   0.23   0.10   0.06   0.20   0.27   0.17   0.08   0.08   0.10   0.08   0.11   0.18   0.23   0.24   0.21   0.16   0.11   0.08   0.11   0.23
12  5 8 1.0   0.19   0.05   0.06   0.15   0.09  -0.06  -0.10  -0.03   0.01   0.01  -0.01  -0.03  -0.07  -0.09  -0.11  -0.15  -0.20  -0.26  -0.33  -0.42  -0.52
12  6 5 1.0   5.76   5.79   5.79   5.69   5.88   6.22   6.16   5.83   5.75   5.88   5.93   6.07   6.45   6.63   6.23   5.68   5.75   6.31   6.08   3.59   2.00
12  6 6 1.0   5.76   5.93   5.95   5.57   5.32   5.49   5.62   5.53   5.55   5.71   5.69   5.50   5.40   5.32   4.97   4.47   4.29   4.50   4.38   2.91   2.00
12  6 7 1.0   4.43   4.64   5.14   5.11   4.78   4.85   5.07   4.99   4.84   4.91   5.01   5.02   5.07   5.07   4.78   4.43   4.62   5.37   5.70   4.23   2.00
12  6 8 1.0   4.43   4.79   4.92   4.70   4.79   5.07   5.04   5.02   5.38   5.61   5.31   5.01   5.26   5.60   5.32   4.71   4.64   5.31   5.76   4.62   2.00
12  7 5 1.0   0.68   0.54   0.43   0.50   0.57   0.50   0.46   0.46   0.32   0.13   0.23   0.55   0.71   0.63   0.58   0.67   0.68   0.49   0.43   1.08   2.80
12  7 6 1.0   0.68   0.71   0.75   0.77   0.64   0.49   0.52   0.57   0.44   0.32   0.40   0.54   0.52   0.38   0.33   0.45   0.61   0.65   0.56   0.49   0.54
12  8 5 1.0  -0.09  -0.09  -0.11  -0.16  -0.22  -0.25  -0.29  -0.33  -0.34  -0.33  -0.36  -0.43  -0.47  -0.46  -0.48  -0.55  -0.63  -0.67  -0.70  -0.80  -1.02
12  8 6 1.0  -0.09  -0.07  -0.04  -0.01   0.03   0.06   0.09   0.09   0.06   0.02   0.02   0.05   0.08   0.11   0.15   0.22   0.26   0.22   0.15   0.12   0.19
12  9 5 1.0  -0.03   0.00   0.04   0.01  -0.04  -0.01   0.02  -0.02  -0.06  -0.03  -0.00  -0.05  -0.09  -0.06  -0.02  -0.05  -0.11  -0.14  -0.15  -0.26  -0.55
12  9 6 1.0  -0.03   0.00   0.02   0.03   0.05   0.06   0.05   0.04   0.03   0.03   0.06   0.09   0.09   0.07   0.12   0.23   0.31   0.28   0.21   0.24   0.49
....
```

Delta-V for EC-YS Mode Switch

With Delta-V Estimation



Without Delta-V Estimation



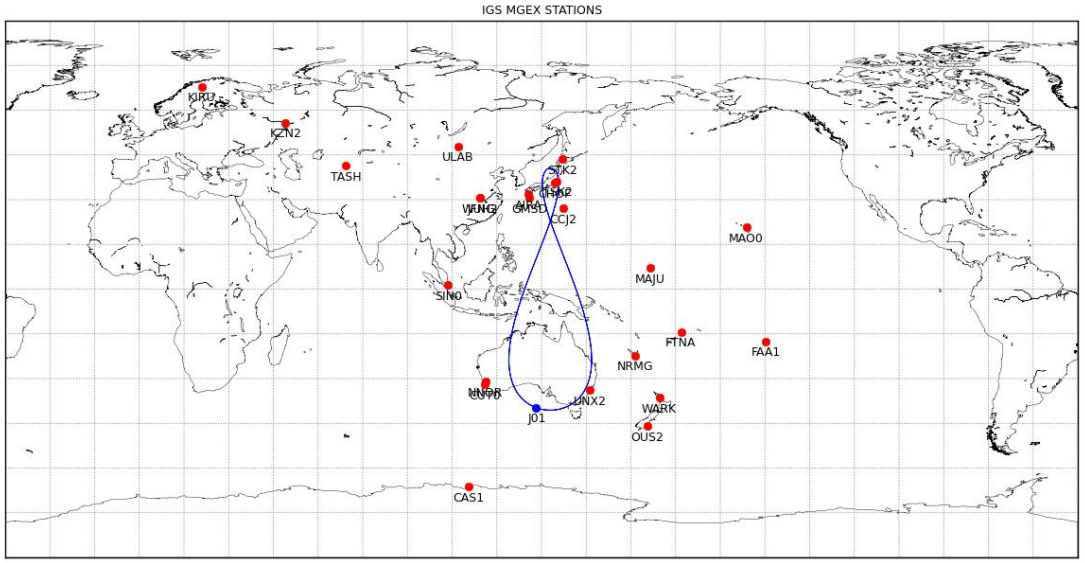
QZSS-1 Orbit Evaluation

Estimation Strategy

- **By MADOCA Batch Estimator (MGEST)**
- **Estimation Arc:**
  24H+48H+24H (every 24 H)
- **OBS data:**
  24 MGEX Stations RINEX Data (300 s)
- **Fixed Parameters:**
  GPS Orbit (IGS Final), EOP (IGS Final) and Station Position (Estimated by PPP by GPS only)
- **Estimated Parameters:**
  QZS Orbit, QZS/GPS Clock, ZTD and Gradient, Ambiguity, GPS-QZS Receiver Bias

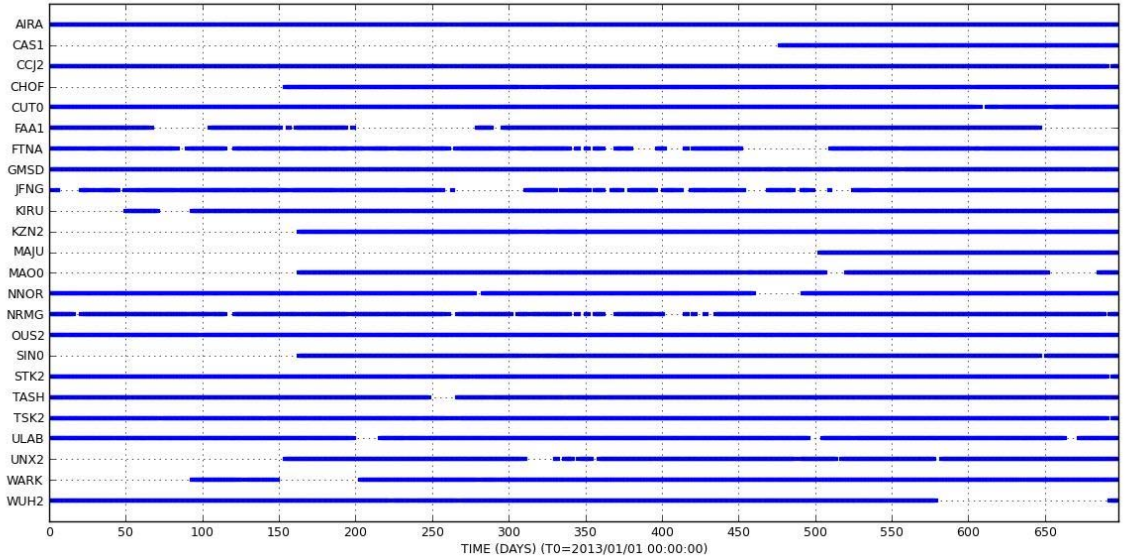
MGEX Stations

MGEX
24 Station
Positions



AIRA CAS1 CCJ2
CHOF CUT0 FAA1
FTNA GMSD JFNG
KIRU KZN2 MAJU
MAO0 NNOR NRMG
OUS2 SIN0 STK2
TASH TSK2 ULAB
UNX2 WARK WUH2

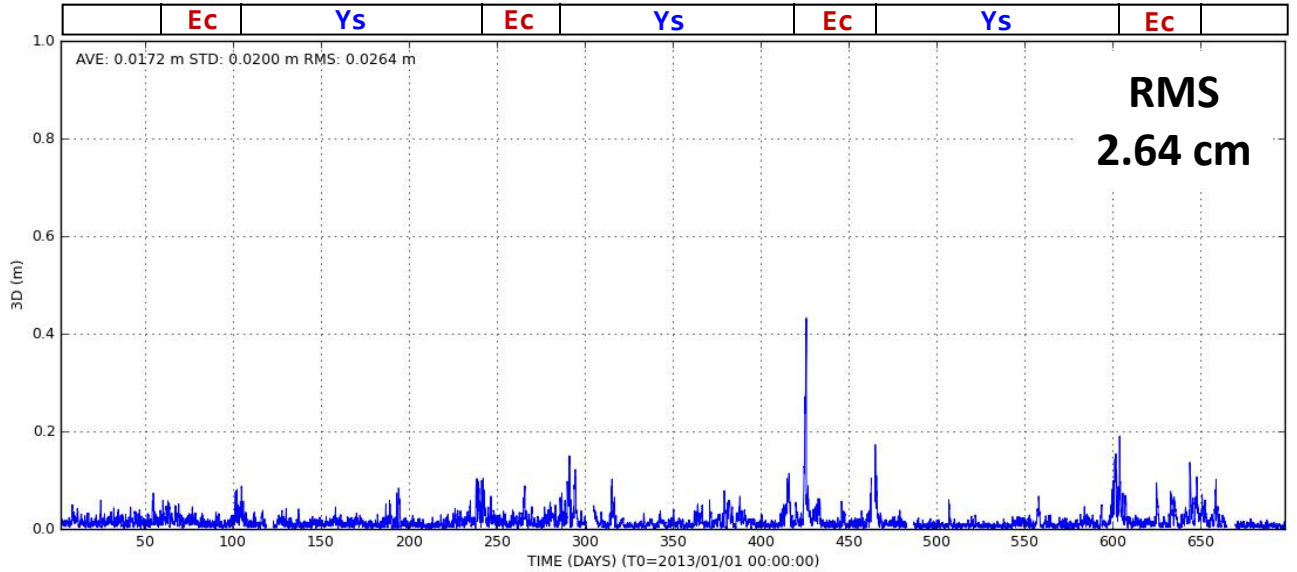
MGEX
Data
Availability



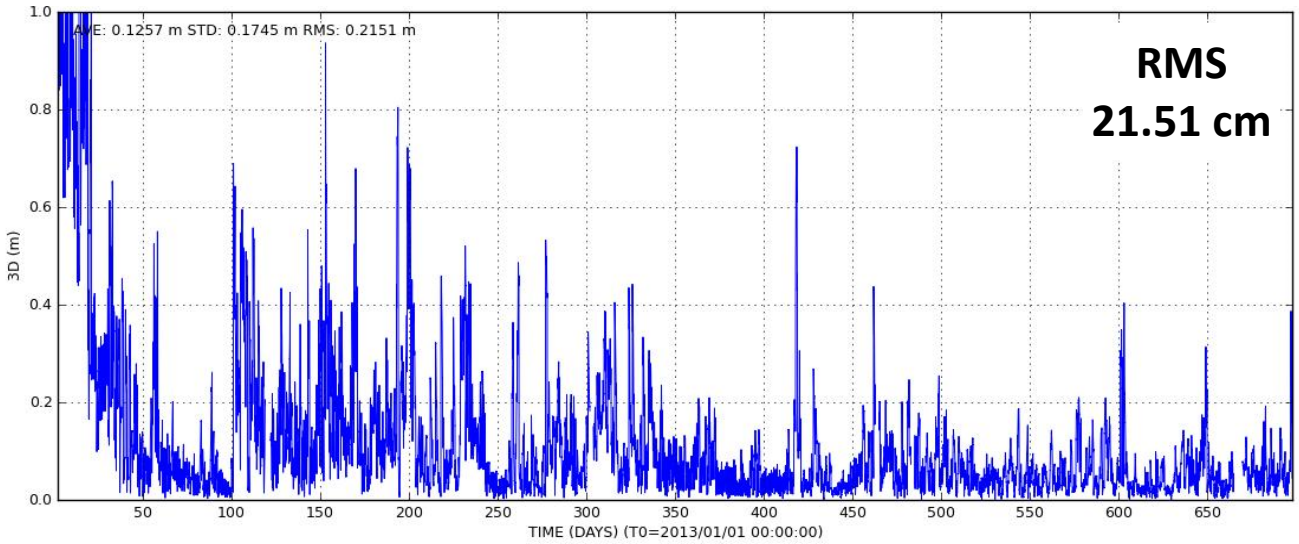
2013/01/01
~
2014/11/30

24H Orbit Overlap (3D)

MADOCA 0.7.0 EDBY



MADOCA 0.6.7 MDBY



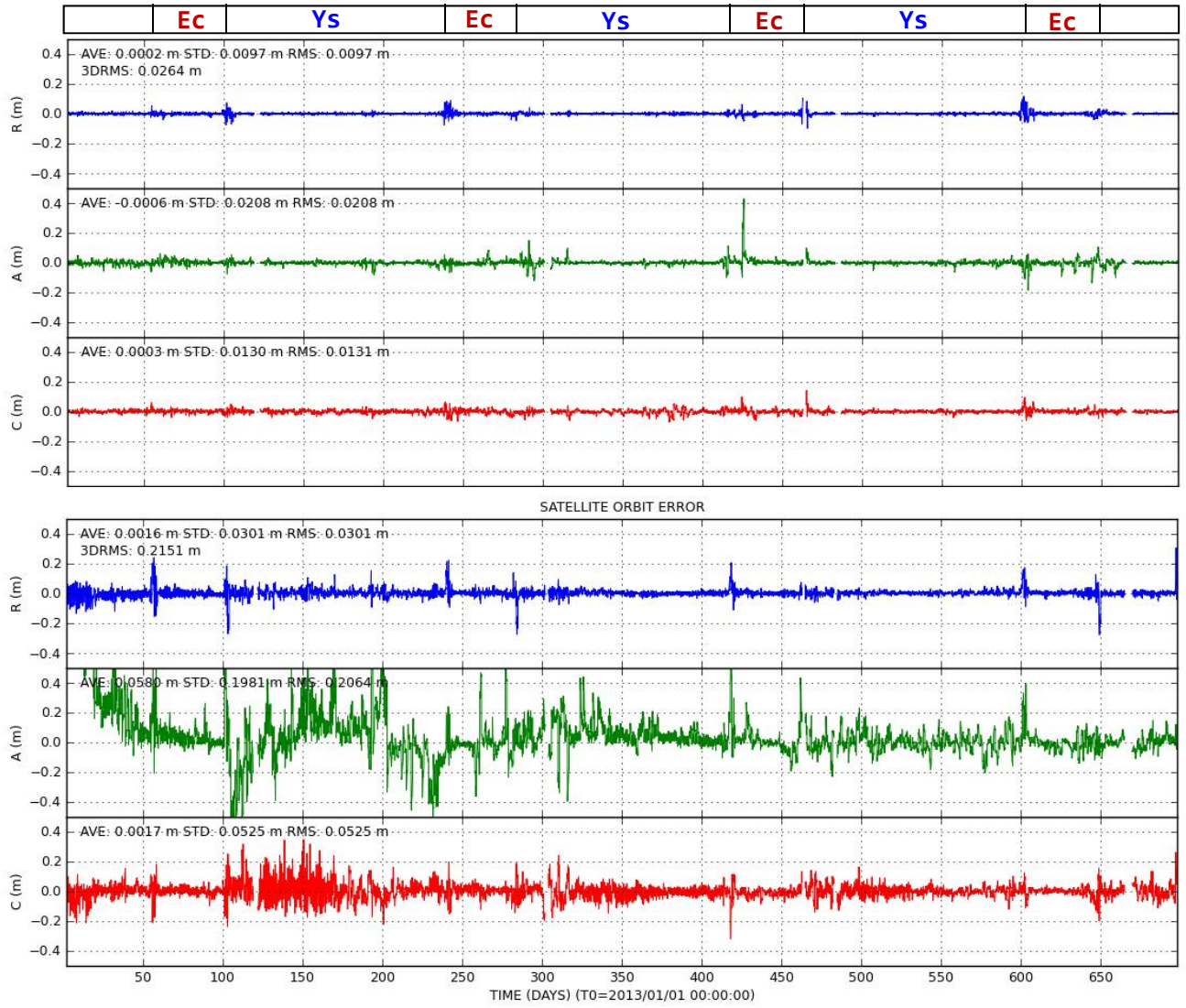
24H Orbit Overlap (RAC)

MADOCA 0.7.0 EDBY

RMS
R 0.97 cm
A 2.08 cm
C 1.31 cm

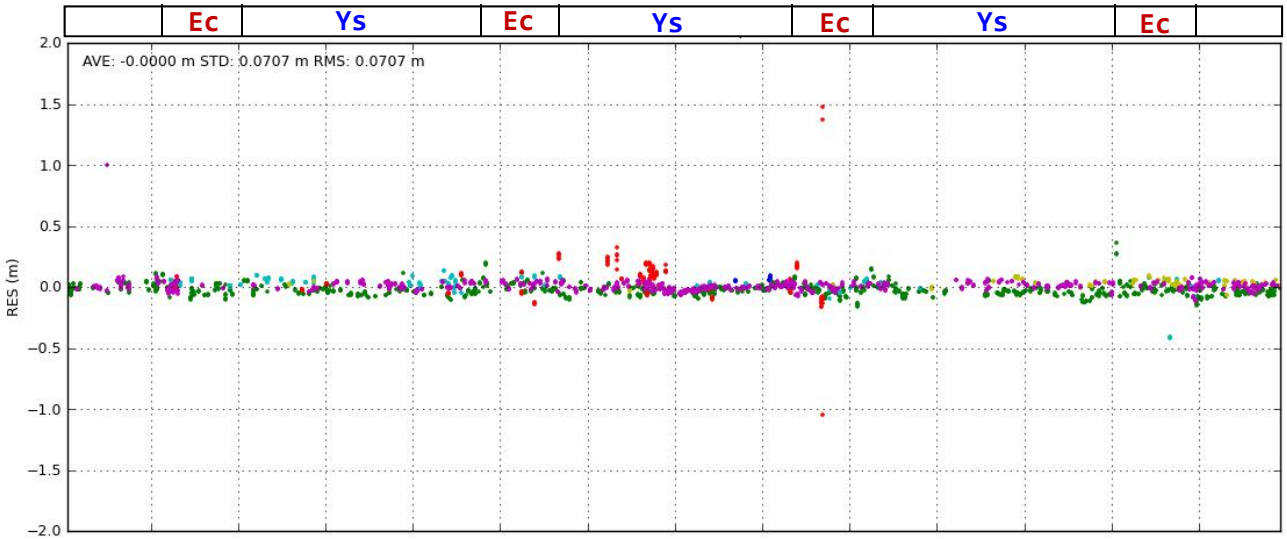
MADOCA 0.6.7 MDBY

RMS
R 3.01 cm
A 20.64 cm
C 5.25 cm

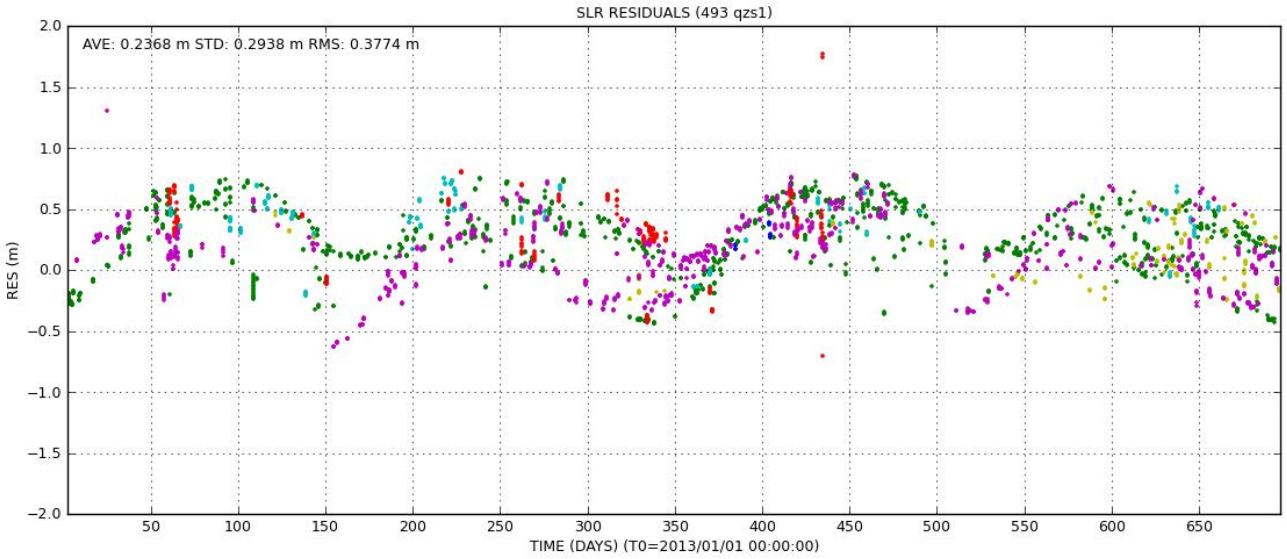


SLR Residuals (1/2)

MADOCA 0.7.0 EDBY



RMS 7.07 cm

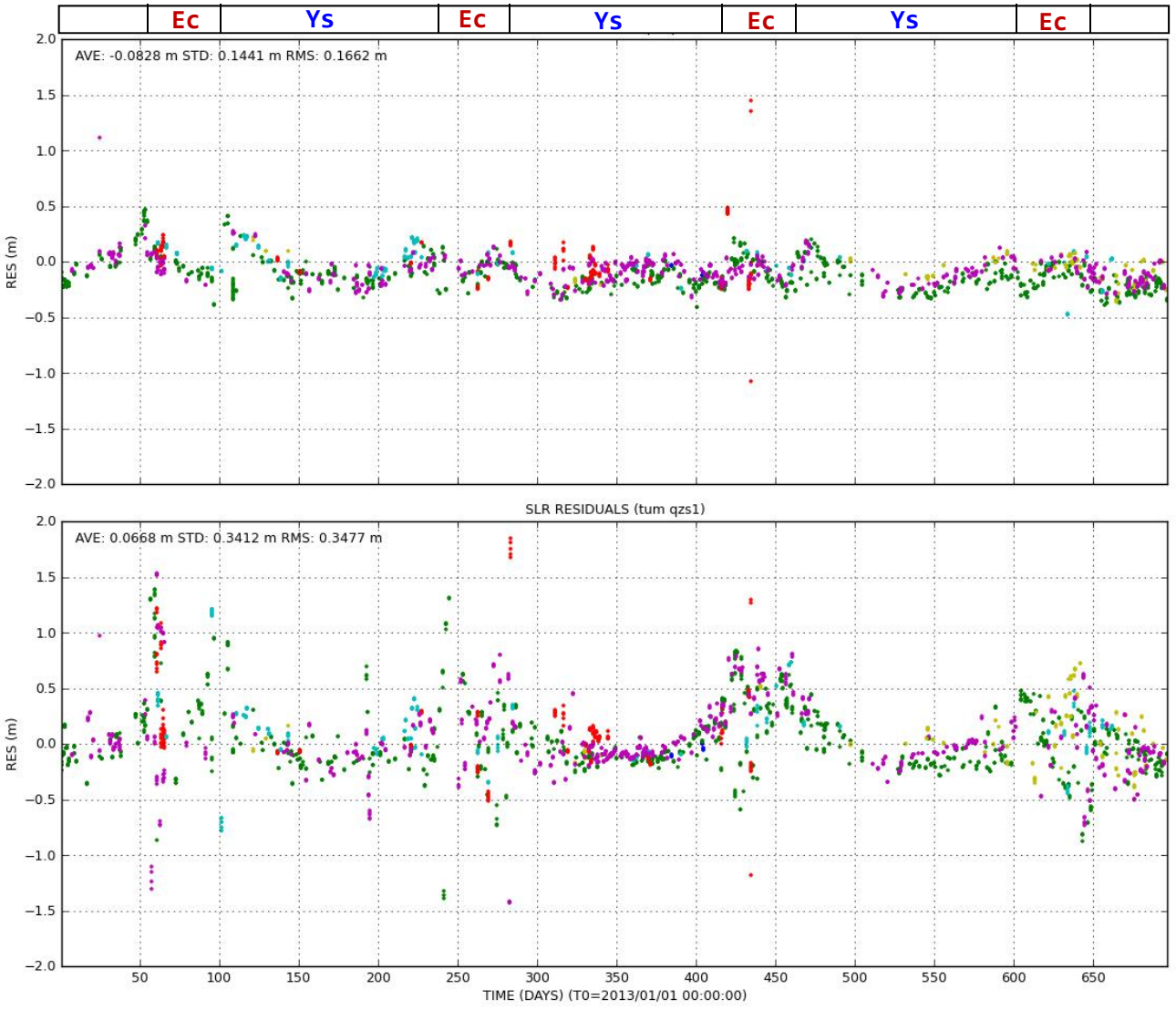


MADOCA 0.6.7 MDBY

RMS 37.74 cm

SLR Residuals (2/2)

QZS Final Product



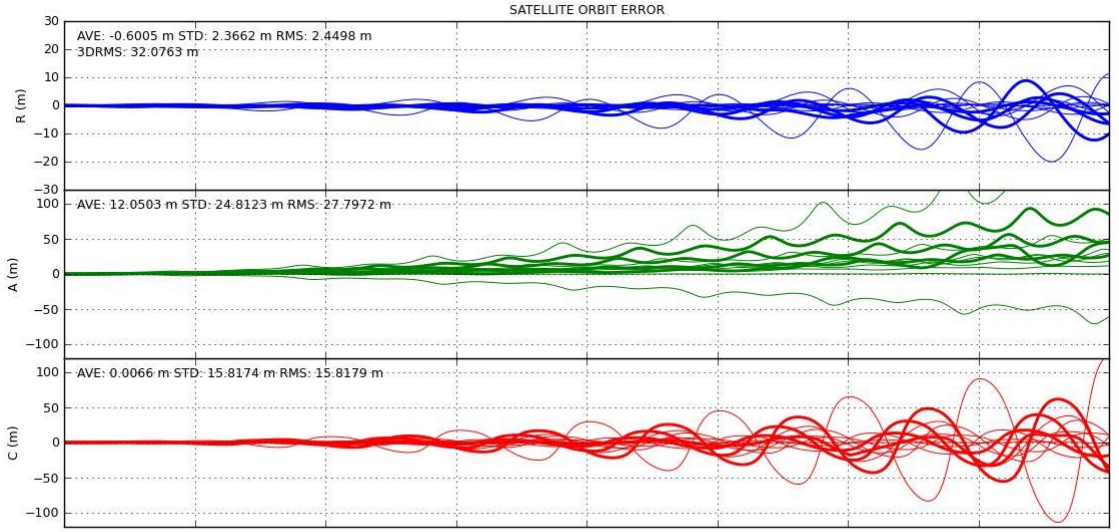
RMS 16.62 cm

IGS TUM Product

RMS 34.77 cm

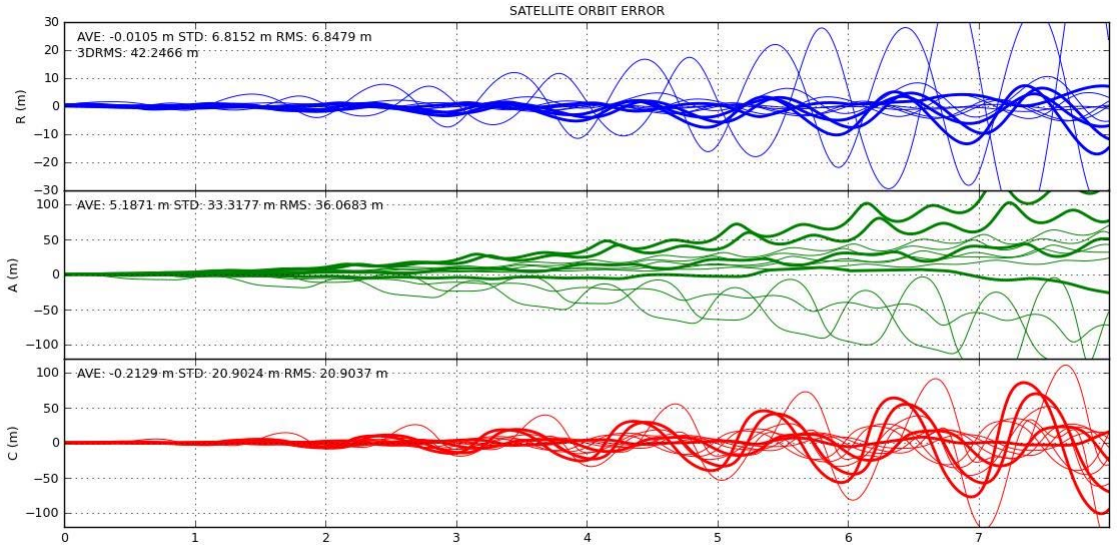
Orbit Predicted - Estimated

MADOCA
0.7.0
EDBY



RMS
R 2.45 m
A 27.79 m
C 15.82 m

MADOCA
0.6.7
MDBY



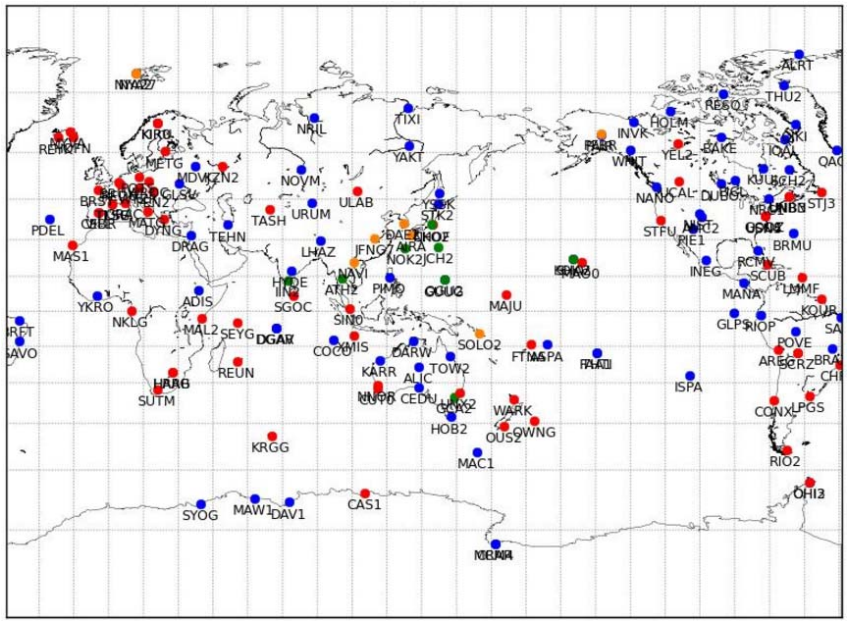
RMS
R 6.85 m
A 36.07 m
C 20.90 m

(12 cases)

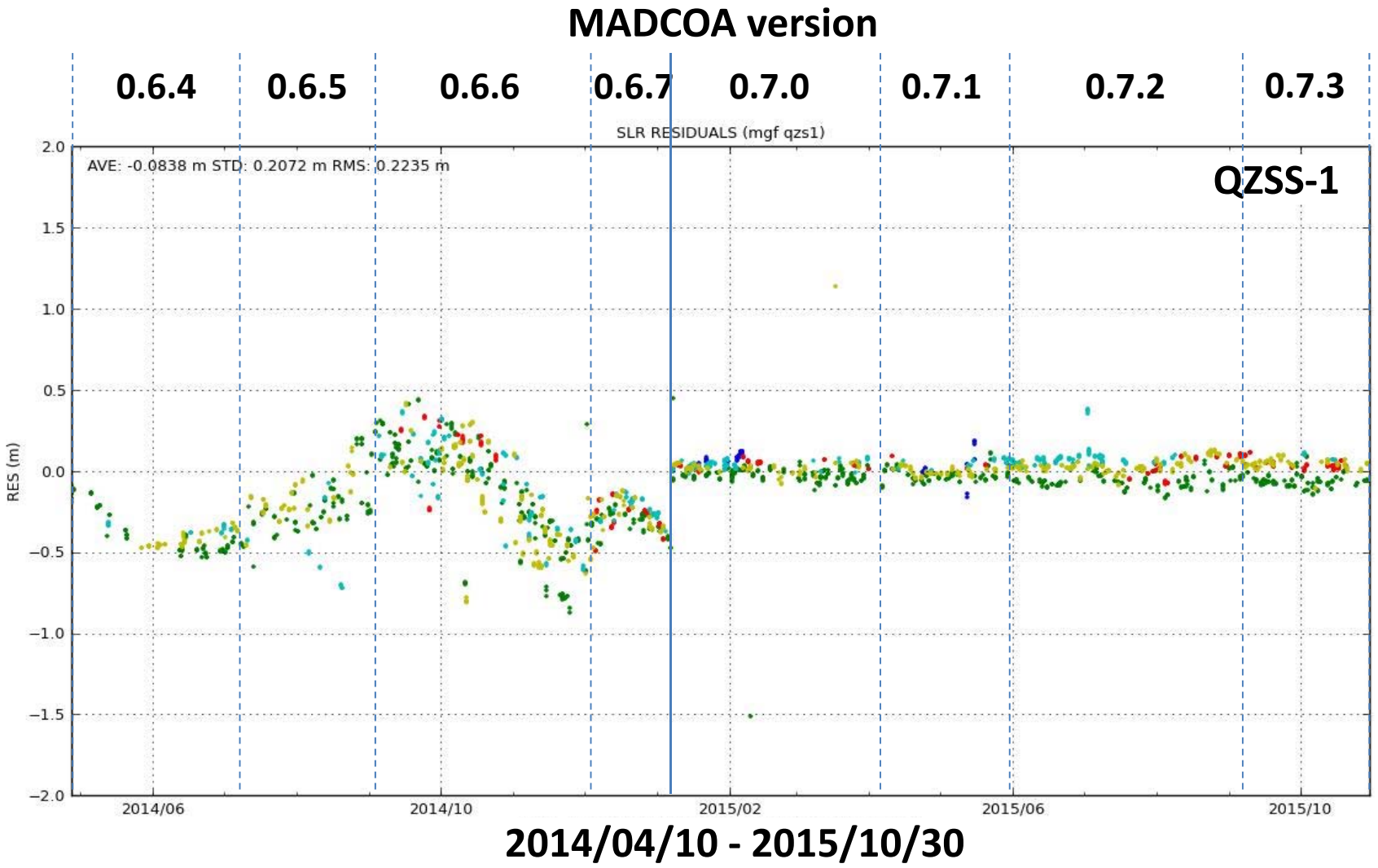
0 - 7 days

Routine Products (MGF)

- **For evaluation and validation of MADOCA**
- **Daily (Latency: 37 - 61 H), Arc: 3H+24H+3H**
- **Satellites:**
  GPS/GLO/QZS (2014/4~), GAL (2015/3~),
  BDS (2015/10~),
- **Products:**
  SP3 Orbit, RINEX CLK (30s),
  EOP, AMB, FCB (2014/8~)
- **# of Stations: 152**
  IGS, MGEX, QZSS-MS,
  MGM-NET



SLR Residuals of MGF



Summary

- **MADOCA and QZSS-1 Overview**
- **QZSS-1 Orbit Determination**
  - Force Models
  - Parameter Adjustment
  - SRP Model
  - Handling of EC-YS Mode Switch
- **QZSS-1 Orbit Evaluation**
  - 24H Orbit Overlap
  - SLR Residuals
  - Orbit Predicted - Estimated
  - Routine Products (MGF)