GLONASS-VLBI: Onsala-Wettzell test observations

R. Haas, T. Hobiger, A. Hellerschmied, A. Neidhardt, J. Kodet

Abstract A series of VLBI observations of GLONASS signals were performed in January 2014 on the baseline Onsala–Wettzell. Several GLONASS satellites were observed in alternating mode, the resulting data were correlated and fringes were successfully found. The results prove that signal-to-noise-ratio (SNR) on the order of 50 can be achieved with just 2 s of observations already. It appears however important to chose appropriate attenuation at the stations to receive the strong satellite signals. Furthermore, the rather simple a priori delay model used for the correlation needs to be improved in order to be able to derive phase delays.

Keywords GLONASS, VLBI, DiFX, Fourfit

1 Introduction

Since several years the question of how to connect the reference frames of the various space geodetic techniques is a topic of continual discussion. Currently, the production of the International Terrestrial reference Frame (ITRF) (Altamimi et al., 2011) depends heavily on so-called co-location stations that are equipped with instruments for several space geodetic techniques. Accurate information on the so-called local-tie vectors between the reference points of the instruments is needed in order to be able to connect the different space geodetic techniques. For various reasons the quality of the local-tie vectors appears not to be equal at all co-location stations and in some cases is heavily debated (Ray and Altamimi, 2005). Thus, to improve the connection of the different space geodetic techniques, ideas have been developed to achieve co-location in space as a complement to co-location on the ground.

One idea is to launch low earth orbiting (LEO) satellites that are equipped with receiving instruments for GNSS signals, retro-reflectors for Satellite Laser Ranging (SLR), and transmitters for artificial VLBI signals (Bar-Sever et al., 2014). A first satellite following this approach has been launched recently (Geshi, 2015) and it is to be expected that first VLBI observations of this satellite will be done soon.

Another idea is to observe GNSS signals directly with VLBI telescopes (e.g. Tornatore et al. (2011)). However, since GNSS signals are in the L-band, radio telescopes with L-band receivers are needed for such observations while today's normal geodetic VLBI observations use S- and X-band. To realize the observation of GNSS signals with radio telescopes used for geodetic VLBI, an L-band system has been developed at the Wettzell Geodetic Observatory for its 20 m radio telescope (Kodet et al., 2014). This new system extracts the L-band signals through the S-band signal chain. In early 2013 first successful tests have been performed (Haas et al., 2014) together with the Onsala 25 m radio telescope in Sweden, which is equipped with a dedicated L-band system for astronomical VLBI observations. At that time one GLONASS satellite was ob-

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Fig. 1 The 20 m radio telescope at Wettzell (left) and the 25 m radio telescope at Onsala (right).

served for about 45 minutes and fringes were found successfully. Further test observations were performed in early 2014, again using the Onsala–Wettzell baseline. Figure 1 depicts photos of the involved telescopes. In the following we present first results of the 2014 observations.

2 GLONASS-VLBI observations 2014

In January 2014 a series of GLONASS VLBI-observations was scheduled for the Onsala–Wettzell baseline. These observations involved the 25 m radio telescope at Onsala with its dedicated L-band receiving system, and the 20 m radio telescope at Wettzell with its L-band via S-band system (Kodet et al., 2014). The scheduling was done with the satellite-scheduling module of the VieVs software (Hellerschmied et al., 2014) which produced the necessary telescope control files. The observations were planned for several hours on January 16 and 21. In total eight GLONASS satellites were observed in an alternating mode, i.e. switching between the satellites, with observations of several minutes, see Table 1. Since the satellite signals are much stronger than the signals of natural radio sources, at Onsala additional attenuation had to be added in order to avoid saturation of the L-band receiving system. For the observations on Jan. 16 additional attenuation of 10 dB was used, while for the observations on Jan. 21 even 30 dB were used. In contrast to that, at Wettzell, the weak L-band signal that passes through the S-band horn needed to be amplified by about 30 dB.

Table 1 Overview of the GLONASS-VLBI observations in January 2014. Given are the observing times, the GLONASS, NORAD and PR numbers of the satellites.

Date	UT-Time	GLONASS	NORAD	PR
2014-01-16	12:30-12:45	743	37869	PR08
	12:50-13:05	723	32395	PR11
	13:10-13:25	730	36111	PR01
	14:00-14:15	730	36111	PR01
	14:20-14:35	737	37138	PR12
	14:40-15:00	747	39155	PR02
2014-01-21	13:30-13:35	743	37869	PR08
	13:37-13:42	732	36402	PR23
	13:44.13:49	743	37869	PR08
	13:51-13:56	732	36402	PR23
	13:59-14:04	743	37869	PR08
	14:08-14:13	735	36401	PR24
	14:14-14:19	”	”	”
	14:25-14:30	732	36402	PR23
	15:00-15:04	735	36401	PR24
	15:05-15:09	”	”	”
	15:10-15:14	”	”	”
	15:20-15:24	746	37938	PR17
	15:25-15:29	”	”	”
	15:30-15:34	”	”	”
	15:45-15:49	723	32395	PR11
	15:50-15:54	”	”	”
	15:55-16:00	”	”	”

3 Data processing

The correlation of the observed data was done with Version 2.3 of the software correlator DiFX (Deller et al., 2011), which is installed at the Onsala Space Observatory. The necessary a priori delay values were externally calculated with a simple model following Moyer (2000). Every 15 s the a priori delays were expressed as coefficients of a polynomial model and inserted in the control files for the DiFX correlation. Each scan of 15 s length was correlated individually, with 256 lags and 0.16 s accumulation period.

After correlation the resulting files were processed with Fourfit [1]. Examples of fringe plots for all eight GLONASS satellites that were observed are presented in Fig. 2 and Fig. 3. It becomes clear that the higher attenuation used at Onsala on Jan. 21 caused worse correlation results compared to the Jan. 16 observations. For example, the SNR values are lower and the correlation amplitudes and phases are more noisy than for the Jan. 16 observations.

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[1] http://www.haystack.mit.edu/tech/vlbi/hops/fourfit.txt

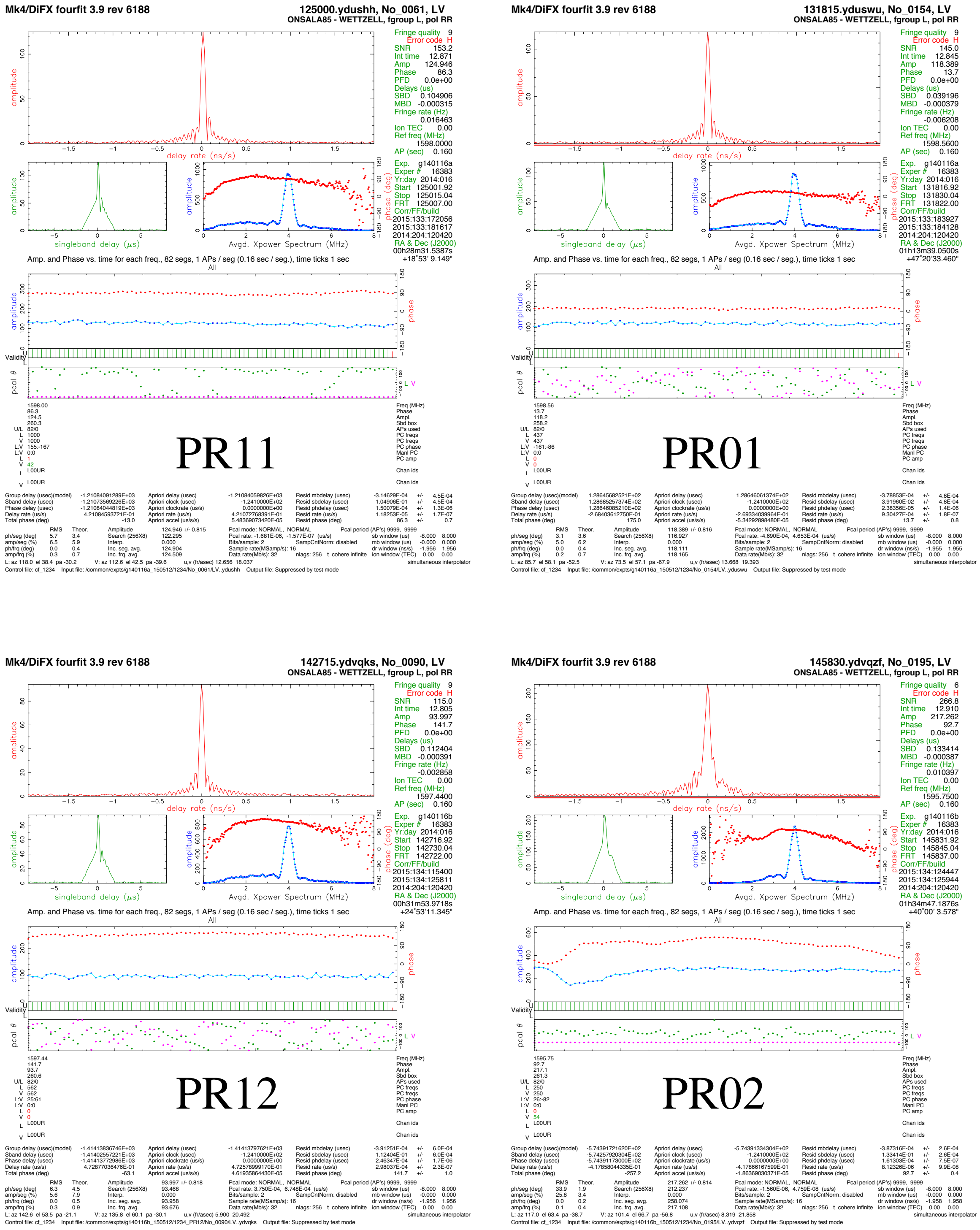
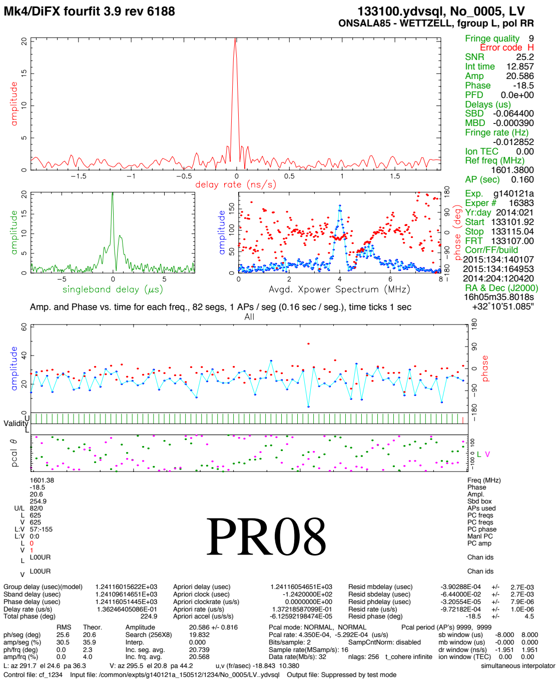


Fig. 2 Examples of fringe plots for GLONASS PR11 (top left), PR01 (top right), PR12 (bottom left) and PR02 (bottom right), observed on January 16, 2014, on the Onsala–Wettzell baseline.



```
Mk4/DiFX fourfit 3.9 rev 6188                         133100.ydvsql, No_0005, LV
                                         ONSALA85 - WETTZELL, fgroup L, pol RR

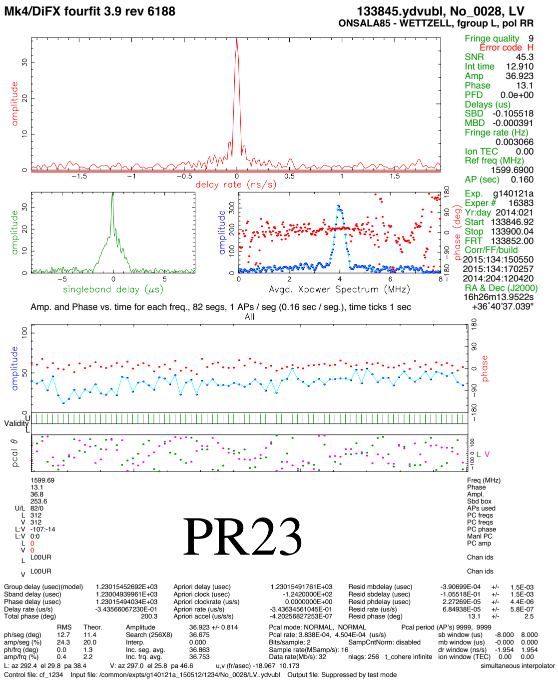
Fringe quality  9
    Error code  H
SNR          25.2
Int time   12.857
Amp        20.586
Phase       -18.5
PFD       0.0e+00
Delays (us)
SBD     -0.064400
MBD     -0.000390
Fringe rate (Hz)
        -0.012852
Ion TEC      0.00
Ref freq (MHz)
        1601.3800
AP (sec)    0.160
Exp.     g140121a
Exper #     16383
Yr:day   2014:021
Start   133101.92
Stop    133115.04
FRT     133107.00
Corr/FF/build
2015:134:140107
2015:134:164953
2014:204:120420
RA & Dec (J2000)
16h05m35.8018s
  +32°10'51.085"

Amp. and Phase vs. time for each freq., 82 segs, 1 APs / seg (0.16 sec / seg.), time ticks 1 sec
All

      1601.38                                                        Freq (MHz)
      -18.5                                                          Phase
      20.6                                                           Ampl.
      254.9                                                          Sbd box
U/L   82/0                                                           APs used
  L   625                                                            PC freqs
  V   625                                                            PC freqs
L:V   57:-155                                                        PC phase
L:V   0:0                                                            Manl PC
  L   0                                                              PC amp
  V   1
      L00UR                                                          Chan ids
  L
      L00UR                                                          Chan ids
  V

Group delay (usec)(model)  1.24116015622E+03  Apriori delay (usec)       1.24116054651E+03  Resid mbdelay (usec)  -3.90288E-04  +/-  2.7E-03
Sband delay (usec)         1.24109614651E+03  Apriori clock (usec)          -1.2420000E+02  Resid sbdelay (usec)  -6.44000E-02  +/-  2.7E-03
Phase delay (usec)         1.24116051445E+03  Apriori clockrate (us/s)       0.0000000E+00  Resid phdelay (usec)  -3.20554E-05  +/-  7.9E-06
Delay rate (us/s)          1.36246405086E-01  Apriori rate (us/s)        1.37218587099E-01  Resid rate (us/s)     -9.72182E-04  +/-  1.0E-06
Total phase (deg)                      224.9  Apriori accel (us/s/s)    -6.12592198474E-05  Resid phase (deg)            -18.5  +/-      4.5

                RMS   Theor.   Amplitude         20.586 +/- 0.816   Pcal mode: NORMAL,  NORMAL          Pcal period (AP's) 9999,  9999
ph/seg (deg)    25.6  20.6     Search (256X8)    19.832             Pcal rate: 4.350E-04,  -5.292E-04  (us/s)   sb window (us)    -8.000  8.000
amp/seg (%)     30.5  35.9     Interp.           0.000              Bits/sample: 2      SampCntNorm: disabled    mb window (us)    -0.000  0.000
ph/frq (deg)    0.0   2.3      Inc. seg. avg.    20.739             Sample rate(MSamp/s): 16                     dr window (ns/s)  -1.951  1.951
amp/frq (%)     0.0   4.0      Inc. frq. avg.    20.568             Data rate(Mb/s): 32  nlags: 256  t_cohere infinite  ion window (TEC)  0.00  0.00
L: az 291.7  el 24.6  pa 36.3      V: az 295.5  el 20.8  pa 44.2      u,v (fr/asec) -18.843  10.380              simultaneous interpolator
Control file: cf_1234   Input file: /common/expts/g140121a_150512/1234/No_0005/LV..ydvsql   Output file: Suppressed by test mode
```



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Mk4/DiFX fourfit 3.9 rev 6188                         133845.ydvubl, No_0028, LV
                                         ONSALA85 - WETTZELL, fgroup L, pol RR

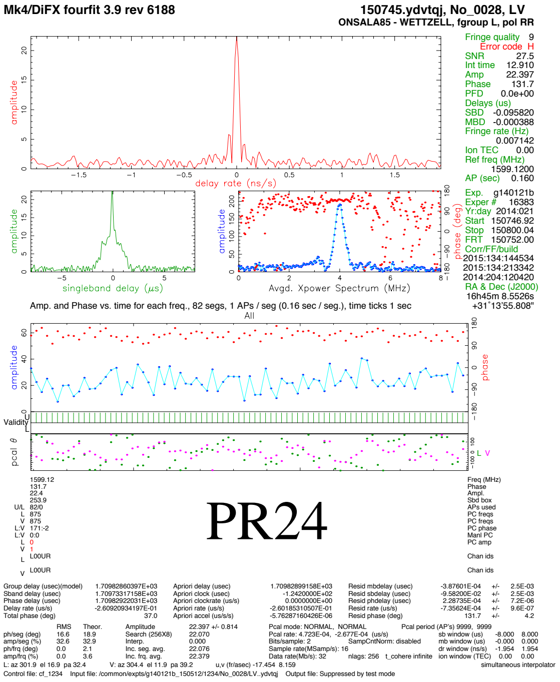
Fringe quality  9
    Error code  H
SNR          45.3
Int time   12.910
Amp        36.923
Phase        13.1
PFD       0.0e+00
Delays (us)
SBD     -0.105518
MBD     -0.000391
Fringe rate (Hz)
         0.003066
Ion TEC      0.00
Ref freq (MHz)
        1599.6900
AP (sec)    0.160
Exp.     g140121a
Exper #     16383
Yr:day   2014:021
Start   133846.92
Stop    133900.04
FRT     133852.00
Corr/FF/build
2015:134:150550
2015:134:170257
2014:204:120420
RA & Dec (J2000)
16h26m13.9522s
  +36°40'37.039"

Amp. and Phase vs. time for each freq., 82 segs, 1 APs / seg (0.16 sec / seg.), time ticks 1 sec
All

      1599.69                                                        Freq (MHz)
      13.1                                                           Phase
      36.8                                                           Ampl.
      253.6                                                          Sbd box
U/L   82/0                                                           APs used
  L   312                                                            PC freqs
  V   312                                                            PC freqs
L:V   -107:-14                                                       PC phase
L:V   0:0                                                            Manl PC
  L   0                                                              PC amp
  V   0
      L00UR                                                          Chan ids
  L
      L00UR                                                          Chan ids
  V

Group delay (usec)(model)  1.23015452692E+03  Apriori delay (usec)       1.23015491761E+03  Resid mbdelay (usec)  -3.90699E-04  +/-  1.5E-03
Sband delay (usec)         1.23004939961E+03  Apriori clock (usec)          -1.2420000E+02  Resid sbdelay (usec)  -1.05518E-01  +/-  1.5E-03
Phase delay (usec)         1.23015494034E+03  Apriori clockrate (us/s)       0.0000000E+00  Resid phdelay (usec)   2.27269E-05  +/-  4.4E-06
Delay rate (us/s)         -3.43566067230E-01  Apriori rate (us/s)       -3.43634561045E-01  Resid rate (us/s)      6.84938E-05  +/-  5.8E-07
Total phase (deg)                      200.3  Apriori accel (us/s/s)    -4.20256827253E-07  Resid phase (deg)             13.1  +/-      2.5

                RMS   Theor.   Amplitude         36.923 +/- 0.814   Pcal mode: NORMAL,  NORMAL          Pcal period (AP's) 9999,  9999
ph/seg (deg)    12.7  11.4     Search (256X8)    36.675             Pcal rate: 3.838E-04,  4.504E-04  (us/s)    sb window (us)    -8.000  8.000
amp/seg (%)     24.3  20.0     Interp.           0.000              Bits/sample: 2      SampCntNorm: disabled    mb window (us)    -0.000  0.000
ph/frq (deg)    0.0   1.3      Inc. seg. avg.    36.863             Sample rate(MSamp/s): 16                     dr window (ns/s)  -1.954  1.954
amp/frq (%)     0.4   2.2      Inc. frq. avg.    36.753             Data rate(Mb/s): 32  nlags: 256  t_cohere infinite  ion window (TEC)  0.00  0.00
L: az 292.4  el 29.8  pa 38.4      V: az 297.0  el 25.8  pa 46.6      u,v (fr/asec) -18.967  10.173              simultaneous interpolator
Control file: cf_1234   Input file: /common/expts/g140121a_150512/1234/No_0028/LV..ydvubl   Output file: Suppressed by test mode
```



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Mk4/DiFX fourfit 3.9 rev 6188                         150745.ydvtqj, No_0028, LV
                                         ONSALA85 - WETTZELL, fgroup L, pol RR

Fringe quality  9
    Error code  H
SNR          27.5
Int time   12.910
Amp        22.397
Phase       131.7
PFD       0.0e+00
Delays (us)
SBD     -0.095820
MBD     -0.000388
Fringe rate (Hz)
         0.007142
Ion TEC      0.00
Ref freq (MHz)
        1599.1200
AP (sec)    0.160
Exp.     g140121b
Exper #     16383
Yr:day   2014:021
Start   150746.92
Stop    150800.04
FRT     150752.00
Corr/FF/build
2015:134:144534
2015:134:213342
2014:204:120420
RA & Dec (J2000)
16h45m 8.5526s
  +31°13'55.808"

Amp. and Phase vs. time for each freq., 82 segs, 1 APs / seg (0.16 sec / seg.), time ticks 1 sec
All

      1599.12                                                        Freq (MHz)
      131.7                                                          Phase
      22.4                                                           Ampl.
      253.9                                                          Sbd box
U/L   82/0                                                           APs used
  L   875                                                            PC freqs
  V   875                                                            PC freqs
L:V   171:-2                                                         PC phase
L:V   0:0                                                            Manl PC
  L   0                                                              PC amp
  V   1
      L00UR                                                          Chan ids
  L
      L00UR                                                          Chan ids
  V

Group delay (usec)(model)  1.70982860397E+03  Apriori delay (usec)       1.70982899158E+03  Resid mbdelay (usec)  -3.87601E-04  +/-  2.5E-03
Sband delay (usec)         1.70973317158E+03  Apriori clock (usec)          -1.2420000E+02  Resid sbdelay (usec)  -9.58200E-02  +/-  2.5E-03
Phase delay (usec)         1.70982922031E+03  Apriori clockrate (us/s)       0.0000000E+00  Resid phdelay (usec)   2.28735E-04  +/-  7.2E-06
Delay rate (us/s)         -2.60920934197E-01  Apriori rate (us/s)       -2.60185310507E-01  Resid rate (us/s)     -7.35624E-04  +/-  9.6E-07
Total phase (deg)                       37.0  Apriori accel (us/s/s)    -5.76287160426E-06  Resid phase (deg)            131.7  +/-      4.2

                RMS   Theor.   Amplitude         22.397 +/- 0.814   Pcal mode: NORMAL,  NORMAL          Pcal period (AP's) 9999,  9999
ph/seg (deg)    16.6  18.9     Search (256X8)    22.070             Pcal rate: 4.723E-04,  -2.677E-04  (us/s)   sb window (us)    -8.000  8.000
amp/seg (%)     32.6  32.9     Interp.           0.000              Bits/sample: 2      SampCntNorm: disabled    mb window (us)    -0.000  0.000
ph/frq (deg)    0.0   2.1      Inc. seg. avg.    22.076             Sample rate(MSamp/s): 16                     dr window (ns/s)  -1.954  1.954
amp/frq (%)     0.0   3.6      Inc. frq. avg.    22.379             Data rate(Mb/s): 32  nlags: 256  t_cohere infinite  ion window (TEC)  0.00  0.00
L: az 301.9  el 16.9  pa 32.4      V: az 304.4  el 11.9  pa 39.2      u,v (fr/asec) -17.454  8.159               simultaneous interpolator
Control file: cf_1234   Input file: /common/expts/g140121b_150512/1234/No_0028/LV..ydvtqj   Output file: Suppressed by test mode
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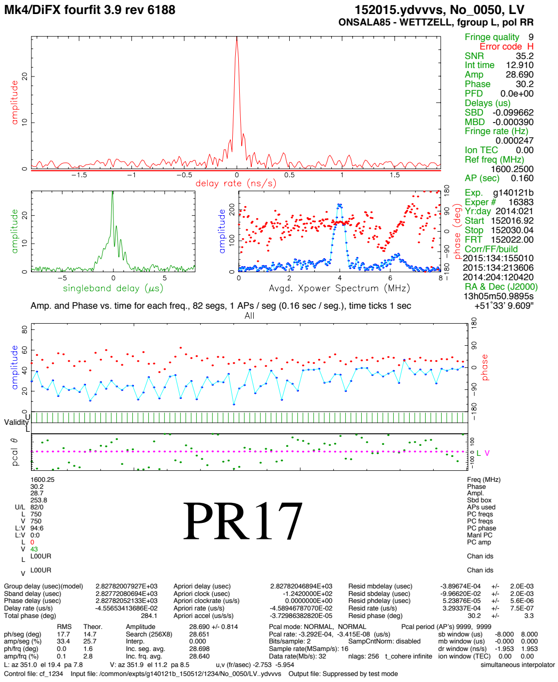

```
Mk4/DiFX fourfit 3.9 rev 6188                         152015.ydvvvs, No_0050, LV
                                         ONSALA85 - WETTZELL, fgroup L, pol RR

Fringe quality  9
    Error code  H
SNR          35.2
Int time   12.910
Amp        28.690
Phase        30.2
PFD       0.0e+00
Delays (us)
SBD     -0.099662
MBD     -0.000390
Fringe rate (Hz)
         0.000247
Ion TEC      0.00
Ref freq (MHz)
        1600.2500
AP (sec)    0.160
Exp.     g140121b
Exper #     16383
Yr:day   2014:021
Start   152016.92
Stop    152030.04
FRT     152022.00
Corr/FF/build
2015:134:155010
2015:134:213606
2014:204:120420
RA & Dec (J2000)
13h05m50.9895s
  +51°33' 9.609"

Amp. and Phase vs. time for each freq., 82 segs, 1 APs / seg (0.16 sec / seg.), time ticks 1 sec
All

      1600.25                                                        Freq (MHz)
      30.2                                                           Phase
      28.7                                                           Ampl.
      253.8                                                          Sbd box
U/L   82/0                                                           APs used
  L   750                                                            PC freqs
  V   750                                                            PC freqs
L:V   94:6                                                           PC phase
L:V   0:0                                                            Manl PC
  L   0                                                              PC amp
  V   43
      L00UR                                                          Chan ids
  L
      L00UR                                                          Chan ids
  V

Group delay (usec)(model)  2.82782007927E+03  Apriori delay (usec)       2.82782046894E+03  Resid mbdelay (usec)  -3.89674E-04  +/-  2.0E-03
Sband delay (usec)         2.82772080694E+03  Apriori clock (usec)          -1.2420000E+02  Resid sbdelay (usec)  -9.96620E-02  +/-  2.0E-03
Phase delay (usec)         2.82782052133E+03  Apriori clockrate (us/s)       0.0000000E+00  Resid phdelay (usec)   5.23876E-05  +/-  5.6E-06
Delay rate (us/s)         -4.55653413686E-02  Apriori rate (us/s)       -4.58946787070E-02  Resid rate (us/s)      3.29337E-04  +/-  7.5E-07
Total phase (deg)                      284.1  Apriori accel (us/s/s)    -3.72986382820E-05  Resid phase (deg)             30.2  +/-      3.3

                RMS   Theor.   Amplitude         28.690 +/- 0.814   Pcal mode: NORMAL,  NORMAL          Pcal period (AP's) 9999,  9999
ph/seg (deg)    17.7  14.7     Search (256X8)    28.651             Pcal rate: -3.292E-04,  -3.415E-08  (us/s)  sb window (us)    -8.000  8.000
amp/seg (%)     33.4  25.7     Interp.           0.000              Bits/sample: 2      SampCntNorm: disabled    mb window (us)    -0.000  0.000
ph/frq (deg)    0.0   1.6      Inc. seg. avg.    28.698             Sample rate(MSamp/s): 16                     dr window (ns/s)  -1.953  1.953
amp/frq (%)     0.1   2.8      Inc. frq. avg.    28.640             Data rate(Mb/s): 32  nlags: 256  t_cohere infinite  ion window (TEC)  0.00  0.00
L: az 351.0  el 19.4  pa 7.8       V: az 351.9  el 11.2  pa 8.5       u,v (fr/asec) -2.753  -5.954               simultaneous interpolator
Control file: cf_1234   Input file: /common/expts/g140121b_150512/1234/No_0050/LV..ydvvvs   Output file: Suppressed by test mode
```

Fig. 3 Examples of fringe plots for GLONASS PR08 (top left), PR23 (top right), PR24 (bottom left) and PR17 (bottom right), observed on January 21, 2014, on the Onsala–Wettzell baseline.

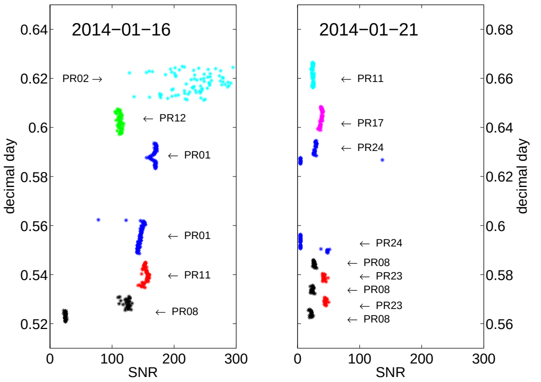

Fig. 4 Signal-to-noise (SNR) values obtained for the observation of Jan. 16 (left plot) and Jan. 21 (right plot).

Figure 4 depicts as an example the SNR values for both days. The data of Jan. 16 consistently gave higher SNR than the data of Jan. 21. Some of the observations did not perform very well, e.g. in the beginning of Jan. 16 with PR08 when one of the telescopes probably was not tracking correctly yet, and about in the middle of Jan. 21 with PR24. The problems on Jan. 21 were due to an operator mistake at Onsala that caused the disconnection of the backend and led to problems with PR24 and a complete loss of the PR23 observations planned directly afterwards (see Table 1).

Additionally, test were performed with the Jan. 16 data using different scans length in Fourfit, between 2 s and 300 s. The results show that SNR of about 50 can already be achieved with 2 s of observed data. Scan length of 15 s give SNR on the order of 150 to 200, while scan length of 300 s give SNR of more than 500.

4 Conclusions and outlook

The GLONASS-VLBI tests performed in January 2014 were successful. The satellite-scheduling module in VieVs was successfully used to plan the observations and to prepare the necessary telescope control files. Several GLONASS satellites could be observed in alternating mode and fringes were successfully found for all satellites. SNR values of 50 could be achieved with scan lengths as short as 2 s. However, the simple a priori delay model used for the correlation turned out to be not sufficiently accurate enough. The observed phases could not be unwrapped successfully and thus it was not possible yet to determine phase delays. A refinement and improvement of this simple delay model is planned for the near future. Furthermore, additional GLONASS-VLBI observations are planned, also using more than just one baseline.

References

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