Recent Progress in GLONASS Time Transfer

W. Lewandowski[1], A. Foks[2], Z. Jiang[1], J. Nawrocki[2], P. Nogaś[2]

[1]Bureau International des Poids et Mesures, Sèvres, France
[2]Astrogeodynamical Observatory, Space Research Center, Borowiec, Poland

Abstract– **Unlike GPS, the GLONASS P-code is broadly accessible. This paper discuss GLONASS capabilities and prospects in terms of precise time transfer. We have tested GLONASS common-view time transfer using the C/A- and P-code, over time links varying in length from about 800 km to 9200 km. The raw GPS and GLONASS data were collected using 3S Navigation receivers, and were corrected using IGS precise orbit data and IGS ionosphere maps. It is proposed that GLONASS time links be calculated monthly, initially as back-up links for TAI calculation, and later as possible official time links.**

I. Introduction

This article is a continuation of studies on GLONASS time transfer [1, 2], which were aimed at introducing the GLONASS into the BIPM TAI time transfer. We have tested GLONASS common-view time transfer using different GLONASS codes (L1C, L1P and L2P), over time links varying in length from about 800 km to 9200 km. The raw GPS and GLONASS data were collected using 3S Navigation receivers, and were corrected using IGS precise orbit data and IGS ionosphere maps. Unlike GPS, almost every GLONASS satellite works at a different basic frequency. In order to study the effects of these different frequencies on the common- view links, the investigations were carried out for every individual satellite. We compared the GLONASS and GPS links measured with the same 3S GPS/GLONASS receivers. For short- and middle-distance time transfers, the GLONASS P-code links show an accuracy of about 1 ns, which is better than that of the GPS C/A-code links. For very long distance links, the accuracy of the P-code links is about 3 ns, which is similar to that of the GPS C/A-code links. This is probably because of the lower accuracy of the IGS GLONASS precise orbit data due to the limited number of world-wide tracking points. It is proposed that GLONASS time links be calculated monthly, initially as back-up links for TAI calculation, and later as possible official time links. We discuss also the behavior of GLONASS time (GLNT).

II. The Experimentation set-up

We discuss here the January 2005 data in CGGTTS format from 3 laboratories: AOS (Poland), VSL (Netherlands) and CSIR (South Africa), equipped with 3S Navigation GPS/GLONASS receivers.

Tab. 1 Approximate distances of the CV links.

Lab2-Lab1	Distance
AOS-VSL	~ 1200 km
CSIR-VSL	~ 9000 km
CSIR-AOS	~ 9200 km

All data were corrected by IGEX/IGS precise orbits and IGS ionosphere maps. In January 2005 we observed 11 satellites with 9 frequencies.

Tab. 2 GLN Satellites/FRC observed in Jan. 2005

Frequency	GLONASS PRN k
1	106
2	105
3	124
4	102
5	117, 121
6	104
10	118, 122
11	123
12	103

The main problem concerns the biases appearing in GLONASS time transfer methods. We should answer the key question of if there are the biases between different GLONASS satellites (frequencies) and how they affect the common view time transfer.

III. GLONASS time realised by the individual PRN

The direct measurement of GLNT is affected by biases between two PRNs:

$$GLNT_{Lab1}^{PRNk} \neq GLNT_{Lab1}^{PRNj} .$$

Those biases do not concern the common view observations but they are important in the access to GLNT.

The previous studies used an arbitrarily chosen PRN as the reference to observe discrepancies between each individual PRN. In this method the common errors, such as the clock or the UTC_{Lab} and the electronic delays are cancelled but the biases depend on the PRN used, and moreover the reference PRN stays unknown.

Therefore we use two other references: UTC_{Lab} and GPS time ($GPST$).

A. Glonass Time with respect to UTC(Lab)

We analyze the variations of GLNT realized by an individual PRN directly, according to the formula

$$GLNT_{Lab}^{PRNk} - UTC_{Lab}.$$

This reference time is continue but affected by the errors of the master clock, the environmental effects on the hardware and it is different for each laboratory.

For the L2P code the biases of each PRN (σ) vary from 6 ns (PRN 105) to 32 ns (PRN 124). The sigma of all the PRNs is about 16 - 17 ns for the 2 laboratories (AOS and VSL). See Figure 1, and Tables 3a and 3b

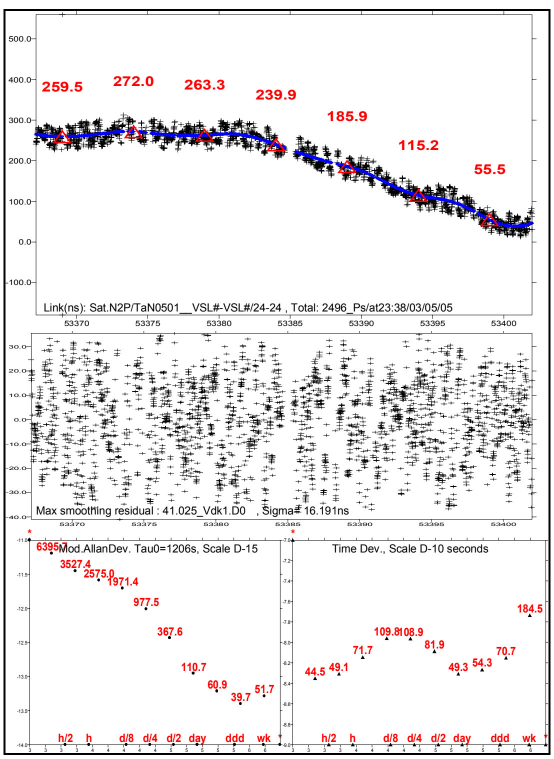

Figure 1. GLNT with respect to UTC(VSL), L2P observations of all PRNs.

B. Glonass Time with respect to GPST

The GPST used here was corrected by the IGS precise orbits, ionosphere maps and the Earth tidal. Its accuracy is of an order of nanoseconds and it is stable enough with respect to the UTC. The GPS and GLONASS signals shared the same receiver, the same antenna and cables and the same clock. In consequence, the common errors are mostly cancelled.

Let $(GLNT - UTC_{Lab})$ and $(GPST - UTC_{Lab})$ be the simultaneous observations of a 3S Navigation receiver at a laboratory, we can compute the variation of the difference of the two satellite time scales:

$$GLNT - GPST = (GLNT - UTC_{Lab}) - (GPST - UTC_{Lab})$$

The biases of each PRN (σ) for the L2P vary from 6 ns (PRN 103) to 32 ns (PRN 124). The sigma of all the PRNs is about 19 ns for the 2 laboratories. See Figure 2 and Tables 4a and 4b.

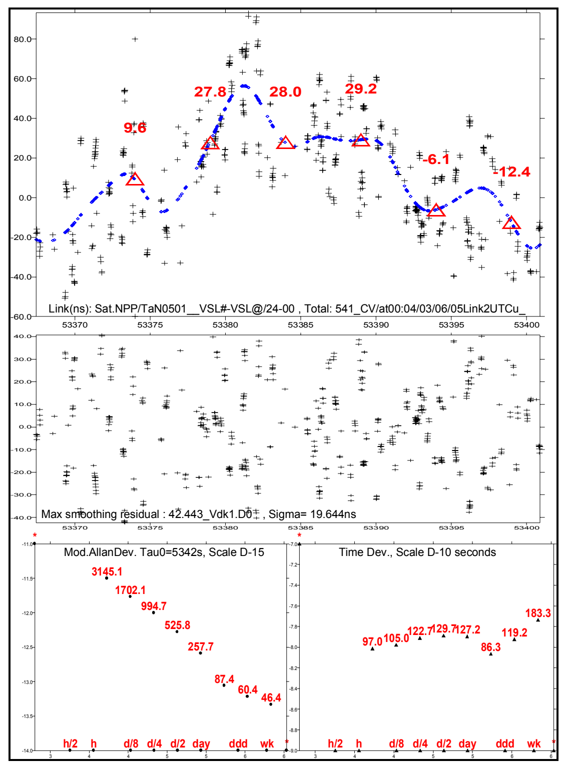

Figure 2. GLNT with respect to GPST, L2P observations of all PRNs.

IV. Common-View

In common view technique, two laboratories receive a signal simultaneously from a single satellite and measure the time difference between this received signal and their own local clock. The basic equation of time transfer between two local laboratories in this technique is:

$$UTC_{Lab2} - UTC_{Lab1} = \left(GLNT_{Lab1}^{PRNk} - UTC_{Lab1}\right) - \left(GLNT_{Lab2}^{PRNk} - UTC_{Lab2}\right)$$

where the equation $GLNT_{Lab1}^{PRNk} = GLNT_{Lab2}^{PRNk}$ should be kept.

For the multi-channel observations the equation becomes:

$$UTC_{Lab2} - UTC_{Lab1} = \frac{1}{N}\sum_{k=1}^{N}\left[\begin{array}{l}\left(GLNT_{Lab1}^{PRNk} - UTC_{Lab1}\right)\\ -\left(GLNT_{Lab2}^{PRNk} - UTC_{Lab2}\right)\end{array}\right]$$

where N is the number of PRNs observed.

A. Glonass and GPS Common-View with the individual PRNs

As shown above, the GLNT is affected by noises and biases depending on PRN. Although not constant, those effects are cancelled in the CV technique. Generally the CV AOS-VSL links computed by the individual PRNs are within 0.5 ns from the mean value for all the PRNs. The PRNs 118 and 122 which have the same frequency give very close CV values, this means that the differences in CV due to different GLONASS frequencies may exist but can be ignored within the measurement accuracy (1 ns).

For the very long distance GLN CV links (CSIR-AOS and CSIR-VSL) the discrepancies between values observed by different PRNs are of 3 ns, it is still within the sigma of the total PRNs.

In comparison with GPS C/A code and P3 code the GLONASS PRNs' "biases" are smaller; for GPS C/A code the discrepancies are of 2 - 4 ns, for P3 code – of 1 ns. However there are advantages of GPS CV: presently there are 18 more GPS satellites then GLONASS and, as a result, more satellites can be seen at any point; in general, the GPS precise orbit is more accurate than that of the GLONASS. See Figure 3 and Tables 5 and 6.

B. Discrepancies between different GLN codes

We observe significant discrepancies between the different codes of the same receiver, for example the mean value for CSIR L2P-L1P is -3.3 ns with sigma 5.9, the same for VSL is 0.3 ns with a sigma 5.3 ns; VSL L1C-L1P is -3.7 ns with sigma 3.0 and for VSL L1C-L2P is –6.3 ns with sigma 3.7. This implies that the CV links and receiver calibrations should be worked out separately for different codes: L1P, L2P and L1C.

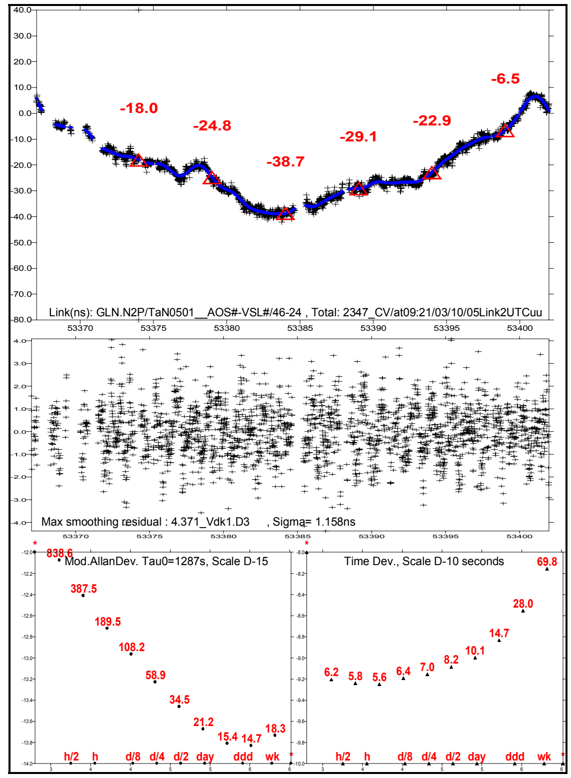

Figure 3. AOS-VSL GLN L2P common view.

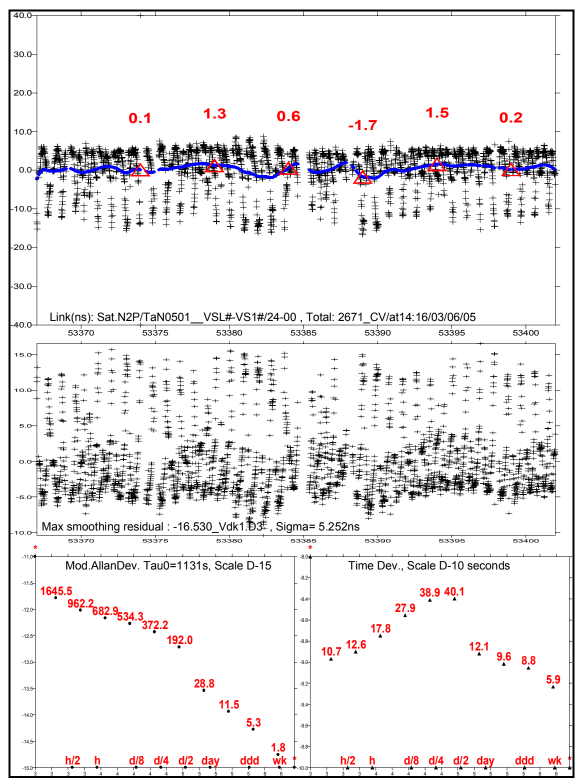

Figure 4. Differences of VSL GLN codes L2P-L1P.

C. Comparison between GLN CV and GPS CV

We can compare the two systems using the GPST as the reference frame for the GLN observations. Considering that the two navigation systems are independent one from another and the comparisons were made at a long distance, the results are better than expected - the sigma is about 1.5 ns. There is a constant bias of about 5 – 7 ns between the two frequencies L1 (codes L1P/ L1C) and L2 (L2P).

Generally the GPS contribution to the sigma results from its poorer solution because of the signal wavelengths and the GLN's share is caused by the lower precision of the IGEX orbits.

The comparisons between GLN and GPS common-view can serve for the differential calibrations of the GLN receivers.

TABBLE. 8. DIFFERENCES OF THE GLN CV AND GPS CV USING DIFFERENT CODES

Link	Dist. /km	Code	Mean	σ	Number
AOS-VSL	1200	P1	-97.36	1.33	355
		C1	-97.64	1.48	31
		P2	-103.82	1.33	2264
CSIR-VSL	9200	P1	-17.98	1.66	551
		C1	-18.07	1.64	32
		P2	-22.25	2.20	526
CSIR-AOS	9000	P1	79.01	1.84	67
		C1	78.73	1.54	19
		P2	81.38	1.81	462

The purpose of this work was to discuss GLONASS capabilities in terms of precise time transfer for TAI needs. We used the data corrected by precise orbits and ionosphere from 3 laboratories forming common view time links varying from 1200 to 9200 km.

We observed non constant biases up to 30 ns in the GLNT realized by different PRNs (FRCs). However they are perfectly cancelled in the CV links.

There are constant biases (up to 7 ns) between CV links observed by different codes (L1C, L1P and L2P) of the same receiver. This confirms the importance of computing CV links separately for each code.

For the CV links from up to 9000 km, the sigma is of 4 – 7 ns for L1C and 1 – 3 ns for the P codes. Generally for middle distance, the GLN P codes are more accurate than the GPS C/A code but seem less accurate for the very long distance, this might be caused by the accuracy of the IGEX precise orbit.

The main disadvantage of GLN is a smaller number of satellites, the number of GLN PRNs observed simultaneously is less than half of that of GPS.

The sigma of the epoch-to-epoch differences of the links computed by using the GPS C/A code and the GLN codes are of 1 – 2 ns. Those results may serve as the differential calibration of the pair of the GLN receivers.

In conclusion, it is suggested to start the GLN CV time link computation as a back-up for GPS CV and TWSTFT operational TAI links, with an ultimate goal of operational GLN P-code CV links. Further studies are necessary.

REFERENCES

[1] J. Azoubib, W. Lewandowski, G. de Jong, J. Nawrocki and J. Danaher, *A New Approach to International Time and Frequency Comparisons: 'All-in-view' Multichannl GPS+GLONASS Observations,* ION GPS'97, 16-19 September 1997.

[1] J. Azoubib and W. Lewandowski, 2000, *Test of GLONASS precise-code time transfer*, Metrologia, 37, pp. 55-59.

[2] J. Azoubib, W. Lewandowski, J. Nawrocki and D. Matsakis, 1999, *Some tests of GLONASS precise-code time transfer*, Proc. Joint EFTF-IEEE IFCS 1999, pp 263-267.

[3] P. Bogdanov , A. Gevorkyan and V. Zholnerov, 1998, *Results of RIRT's comparisons via Glonass signals*, Proc. 30th PTTI, pp 211-218.

[4] Z. Jiang and W. Lewandowski, 2005, Recent Study on GLONASS Time Transfer, BIPM TM136.

[5] Z. Jiang and G. Petit, 2005, *Evaluation of the Effects of the IGEX/IGS Corrections on the GLN Time and GLN Time transfer*, BIPM TM135

[6] W. Lewandowski, J. Nawrocki, J. Azoubib, 2001, *First use of IGEX precise ephemerides for intercontinental GLONASS P-code time transfer*, Journal of Geodesy (2001) 75, pp. 620-625.

[7] F. Roosbeek, P. Defraigne, C. Bruyninx, 1999, *Time transfer using P-code measurements from GPS/GLONASS receivers*, Proc. 31st PTTI, pp 373-382.

TAB. 3A. *GLNT* REALIZED BY THE INDIVIDUAL PRN REFERRED TO UTC(VSL)

PRN	**σ [ns]**	53369	53379	53389	53399	**Mean**	Numb.
ALL	**16.19**	**259.47**	**263.27**	**185.89**	**55.51**	**198.74**	**2496**
102	13.63	242.25	260.37	165.70	53.62	186.87	660
103	6.74	244.03	241.39	161.85	44.84	178.68	674
104	10.82	255.67	252.41	177.24	52.20	192.83	602
105	6.24	244.50	240.25	160.94	33.51	174.51	522
106	12.08	-	-	-	-	-	392
117	14.56	236.31	262.42	185.49	61.65	194.92	566
118	7.05	281.15	264.37	198.08	83.99	214.53	576
121	18.00	262.11	260.31	205.60	42.06	206.87	540
122	9.06	284.06	271.14	195.94	75.89	215.08	692
123	9.32	262.22	266.34	186.67	64.96	200.33	657
124	31.94	241.38	267.71	181.58	29.68	195.15	499

TAB. 3B. GLNT REALISED BY THE INDIVIDUAL PRN REFERRED TO UTC(AOS)

PRN	**σ [ns]**	53369	53379	53389	53399	**Mean**	Numb.
ALL	**16.70**	97.96	106.28	40.74	-48.15	**52.57**	2393
102	12.93	85.80	107.94	24.04	-53.59	41.32	525
103	6.31	89.38	83.80	10.35	-59.08	33.65	576
104	9.85	95.34	95.58	18.28	-47.47	46.54	486
105	8.44	85.48	77.89	14.39	-70.76	28.54	497
106	13.36	-	-	-	-	-	357
117	12.46	70.51	103.27	38.88	-49.03	46.85	487
118	8.36	124.97	106.45	58.02	-21.28	70.78	535
121	15.50	102.89	106.48	62.22	-64.48	59.66	466
122	9.32	119.84	112.76	44.58	-27.27	69.24	582
123	9.42	97.02	109.44	40.39	-38.59	53.82	612
124	32.05	81.82	116.68	41.06	-76.00	45.71	454

TAB. 4A. GLNT REALIZED BY THE INDIVIDUAL PRN REFERRED TO GPST(VSL)

PRN	**σ [ns]**	53374	53384	53389	53399	**Mean**	Numb.
ALL	**19.64**	9.56	28.00	29.25	-12.42	**12.68**	541
102	13.76	-11.36	14.90	3.00	-17.68	2.09	542
103	6.79	-19.34	17.77	-1.00	-23.32	-5.58	569
104	11.14	14.96	24.23	16.90	-24.57	6.55	535
105	6.59	-36.57	24.73	-2.55	-37.16	-11.47	475
106	--	--	--	--	--	--	--
117	13.96	5.53	57.50	19.95	-12.51	13.66	471
118	7.06	24.03	64.28	35.46	12.27	28.64	528
121	18.51	34.59	56.00	43.16	-23.28	23.23	452
122	9.50	62.88	28.60	37.86	7.82	30.34	569
123	9.91	-6.24	49.71	24.19	-2.07	16.09	516
124	32.21	45.97	87.32	2.48	-48.92	15.68	404

TAB. 4B. GLNT REALIZED BY THE INDIVIDUAL PRN REFERRED TO GPST(AOS)

PRN	**σ [ns]**	53374	53384	53389	53399	**Mean**	Numb.
ALL	**18.74**	44.73	48.30	45.09	-18.62	**29.92**	588
102	11.87	16.15	31.86	19.53	-27.78	18.21	404
103	6.43	18.27	39.51	5.36	-25.78	10.26	461
104	9.66	58.66	48.45	13.50	-10.65	24.71	410
105	6.94	3.57	46.96	10.16	-39.55	4.27	371
106	13.49	67.25	84.49	32.67	75.26	74.65	295
117	11.36	43.42	71.21	33.27	-19.38	27.13	376
118	8.51	63.09	88.28	53.26	9.92	47.37	445
121	15.44	73.00	98.46	58.32	-28.62	42.81	371
122	9.13	100.96	53.06	42.54	3.13	46.77	478
123	9.50	29.95	69.03	37.18	-6.23	32.94	509
124	31.94	78.78	54.25	50.90	-47.30	27.33	378

TAB. 5. VSL-AOS GLN COMMON VIEW WITH INDIVIDUAL PRNS P2 CODE

PRN	**σ [ns]**	53374	53384	53389	53399	**Mean**	Numb.	Freq.
ALL	**1.66**	18.53	38.88	28.67	4.50	**22.99**	2347	ALL
102	1.53	18.31	38.35	29.26	5.53	23.11	473	4
103	1.28	17.46	38.19	27.83	5.18	22.57	502	12
104	1.39	18.40	38.88	27.93	6.59	23.32	439	6
105	1.54	18.49	39.03	27.76	5.77	23.20	412	2
106		18.36	38.80	28.92			295	1
117	1.25	18.54	38.21	29.64	5.84	23.14	441	5
118	1.22	17.76	37.95	28.20	5.93	22.52	470	10
121	1.66	16.54		28.52	5.67	22.32	433	5
122	1.68	17.03	38.47	29.13	5.11	22.65	512	10
123	1.30	18.10	38.34	29.53	5.26	22.97	530	11
124	1.36	18.73	38.40	30.37	5.95	23.48	405	3

TAB. 6. VSL-AOS GPS COMMON VIEW WITH THE INDIVIDUAL PRNS

PRN	**C/A code**							**P3 code**						
	σ[ns]	53374	53384	53389	53399	**Mean**	Numb.	σ[ns]	53279	53289	53299	53309	**Mean**	Numb.
ALL	1.88	56.28	60.66	42.42	1.75	**39.94**	2309	1.02	2.86	12.71	18.02	3.75	**10.28**	3528
101	1.34	55.27	59.96	42.95	1.76	39.66	525	1.64	3.62	13.39	17.28	4.18	10.92	818
102	1.55	52.81	63.92	45.97	5.05	42.87	358	-	-	-	-	-	-	-
103	1.38	53.77	57.73	40.67	-0.86	37.33	513	1.00	2.11	12.10	18.70	3.88	10.36	693
104	1.45	59.66	64.08	44.48	3.81	42.79	320	1.57	4.33	14.18	19.23	4.33	11.40	839
105	1.40	53.38	60.05	41.87	0.77	38.99	497	1.19	2.55	12.19	16.65	4.84	10.38	813
106	1.23	55.38	59.92	43.26	2.11	40.05	493	1.33	2.98	11.97	15.79	4.99	9.93	821
107	1.40	58.16	62.62	43.94	3.21	41.54	565	1.49	3.82	13.85	16.86	4.78	11.08	917
108	1.38	53.58	54.90	36.70	-2.63	35.80	309	1.29	2.01	12.84	18.50	2.80	9.94	737
109	1.51	57.11	63.38	44.91	3.85	42.25	407	1.34	2.54	11.43	15.69	3.72	9.86	789
110	1.36	55.29	58.90	41.96	1.93	39.53	382	1.67	3.29	12.76	18.43	2.81	9.98	811
111	1.03	59.16	64.67	46.29	6.04	43.61	447	1.29	1.71	13.45	17.31	3.63	10.35	674
113	1.50	60.28	63.70	44.39	3.63	43.07	349	1.39	4.36	13.26	19.70	4.45	11.39	802
114	1.27	54.65	61.33	43.39	2.22	40.20	563	1.80	2.28	12.43	17.57	2.88	10.25	911
115	1.27	59.03	62.11	45.49	4.57	42.50	481	1.51	2.05	12.31	18.12	4.25	10.42	699
116	1.44	55.46	58.96	43.20	1.26	39.17	429	1.17	1.96	12.01	17.39	5.06	9.97	676
117	1.52	55.05	59.40	42.01	0.89	39.58	495	1.46	3.37	12.89	19.11	3.12	10.22	936
118	1.46	51.39	54.47	37.67	-2.83	35.09	448	1.53	2.51	12.17	17.79	4.60	10.16	895
119	1.42	63.49	68.49	50.92	9.78	47.65	375	1.16	2.09	12.95	17.42	2.70	9.97	631
120	1.15	57.30	61.69	44.49	2.59	41.46	473	1.19	3.27	12.99	16.72	3.92	10.90	780
121	1.51	52.93	56.88	41.17	-0.69	37.16	450	1.55	2.41	11.81	16.77	5.66	9.73	685
122	1.66	55.54	61.35	43.67	2.03	40.26	543	1.39	2.98	11.90	17.63	4.07	10.27	721
123	1.58	52.94	57.58	38.77	-2.93	36.53	343	1.37	3.89	13.26	17.29	4.27	10.99	750
124	1.36	57.38	62.17	45.38	3.30	42.05	326	1.50	3.61	13.95	20.32	4.86	11.42	970
125	1.53	53.59	57.93	40.38	-1.32	37.14	373	1.52	4.81	13.98	19.12	4.50	11.57	909
126	1.28	56.60	60.77	41.93	2.21	40.30	412	1.13	1.34	11.53	17.53	2.86	9.21	721
127	1.16	55.25	56.59	39.16	-1.97	37.38	264	1.77	3.57	13.71	19.01	4.81	11.14	749
128	1.54	52.66	58.90	39.88	0.25	37.94	423	1.58	2.01	14.13	18.87	2.86	10.38	779
129	1.18	54.72	58.88	40.00	0.37	38.62	409	1.27	2.10	12.44	18.45	2.79	9.83	771

TAB. 7A. DIFFERENCES OF GLN CODES L2P-L1P

LAB	σ	53374	53384	53389	53399	Mean	Numb.
VSL	5.25	0.14	0.56	-1.71	0.22	0.33	2671
AOS	3.09	-2.72	-4.08	-3.10	-6.61	-4.06	172
CSIR	5.90	-2.95	-3.49	-4.86	-0.78	-3.30	2701

TAB. 7B. DIFFERENCES OF GLN CODES L1C-L1P

LAB	σ	53374	53384	53389	53399	Mean	Numb.
VSL	2.96	-3.06	-2.54	-3.33	-5.58	-3.67	1739
AOS	1.03	-12.89	-18.87	-15.85	-7.50	-11.47	20
CSIR	0.10	-8.86	-5.20	-8.83	-3.11	-7.74	15

TAB. 7C. DIFFERENCES OF GLN CODES L1C-L2P

LAB	σ	53374	53384	53389	53399	Mean	Numb.
VSL	3.69	-6.94	-4.67	-5.51	-7.66	-6.30	1551
AOS	0.35	21.69	13.81	20.35	21.04	18.27	11
CSIR	0.10	2.12	4.54	6.18	25.40	9.86	6