

Analyses on the Time Series of the Radio Telescope Coordinates of the IVS-R1 and -R4 Sessions

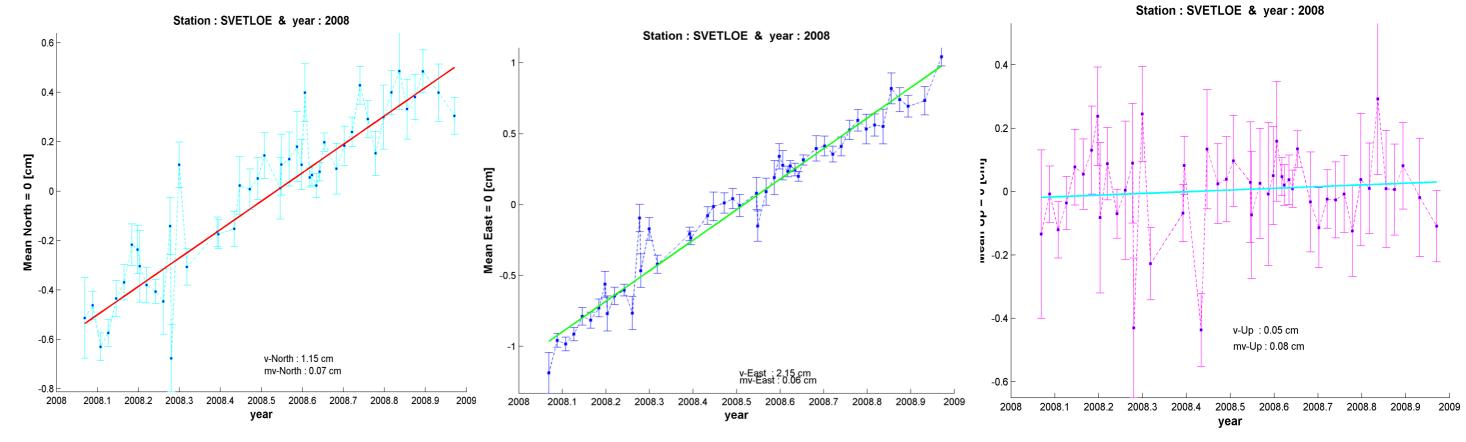
E. Tanir(1), V. Tornatore(2), K. Teke(3,4)
(1) Dept. of Geodesy and Photogrammetry Engineering, Karadeniz Technical University, Turkey
(2) Dept. of Hydraulics, Environmental, Road Infrastracture, Remote Sensing Engineering, Politecnico di Milano, Italy

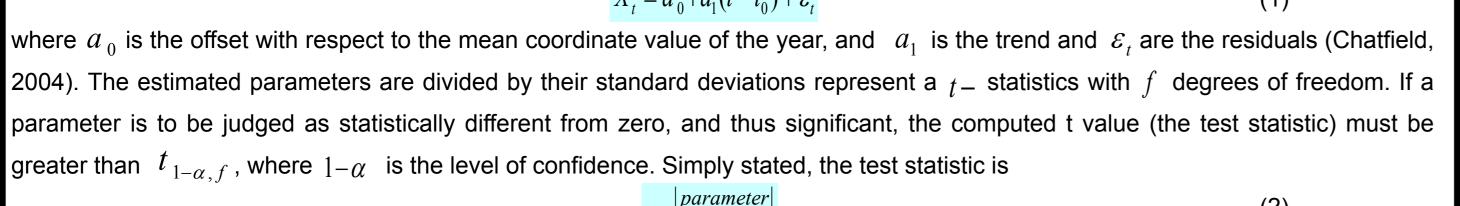
(3) Institute of Geodesy and Geophysics, Vienna University of Technology, Austria

(4) Dept. of Geodesy and Photogrammetry Engineering, Hacettepe University, Turkey

ABSTRACT: In this study, we investigate the coordinate time series of the radio telescopes which regularly take part for IVS-R1 and –R4 sessions. Firstly, we determine the deterministic parts of the series such as linear trend (velocity vectors of the antenna coordinates) due to e.g. crustal movements. Linear trends of the coordinate time series are estimated by least square (LS), fitting the coefficients of a linear regression function. After removing the linear trend from the series, sinusoidal (harmonic) variations of the series if they exist are determined by estimating the amplitude and phase of the Fourier series based on the frequency of the maximum spectral density (power) in the respective spectra plot (periodogram). To sample the data evenly linear interpolation is used. The spectral density of the data is produced by Fast Fourier Transform based on Discrete Fourier Transform. Most of the antennas harmonic variations are not found. Also, the amplitudes of the detected variations are small in ranges between 0.4 - 0.1 mm. This may be caused by the artifacts of the data interpolation or the data it self may not consist any harmonic variations. Because the geophysical models are already applied to the downloaded data (daily sinex normal equations of VLBI sessions provided by Deutsches Geodatisches Forschungsinstitut (DGFI)) except the models of atmosphere loading and thermal deformation.

The determination and removal of the offsets and linear trends (velocities) of coordinates is carried out by LS fit to the linear function. $X_t = a_0 + a_1(t - t_0) + \varepsilon_t$ (1) For further investigations of the coordinates to examine if they contain any sinusoidal variations after the removal of the significant trends fro series spectral analysis should be carried out. However, in Figure 5 from the time series of local topocentric coordinates of the site Svetloe, for year 2008 there is no significant trend in the up direction which means that directly cyclic variations should be investigated for these kinds of series without removing the insignificant trend estimate.





where S is the standard deviation of the parameter. Table 1 shows the site velocities (trends) for the sites of which have adequate estimates (about 50 coordinate estimates per year) also for detecting annual and semi-annual tidal variations.

Sitename	Year	V _{north} (cm)	Veast(cm)	V _{up} cm)	mvn(cm)	mve(cm)	mvu(cm)	num_est	Test(N)	Test(E)	Test(U)	t Significance
ALGOPARK	2001	0.32	-1.68	0.31	0.04	0.02	0.01	57	8.86	77.76	24.47	1.67 + + +
ALGOPARK	2002	-0.04	-1.76	0.23	0.05	0.03	0.02	67	0.72	59.59	14.43	1.67 - + +
ALGOPARK	2003	0.16	-1.62	0.24	0.04	0.03	0.02	55	3.73	51.45	10.10	1.67 + + +
ALGOPARK	2005	0.17	-1.61	0.28	0.04	0.03	0.02	68	4.16	54.82	14.15	1.67 + + +
FORTLEZA	1995	1.19	-0.42	0.01	0.04	0.05	0.03	56	33.02	8.86	0.25	1.67 + + -
FORTLEZA	1996	1.25	-0.49	-0.04	0.05	0.05	0.03	59	22.88	9.53	1.32	1.67 + + -
FORTLEZA	1998	1.29	-0.58	-0.05	0.08	0.06	0.04	53	15.79	8.93	1.26	1.68 + + -
FORTLEZA	1999	1.12	-0.48	0.01	0.05	0.04	0.03	60	23.12	10.95	0.47	1.67 + + -
FORTLEZA	2001	0.89	-0.29	0.12	0.05	0.05	0.03	59	17.15	5.32	4.08	1.67 + + +
FORTLEZA	2003	1.11	-0.43	-0.00	0.06	0.06	0.04	49	17.24	7.03	0.00	1.68 + + -
FORTLEZA	2005	1.18	-0.27	0.01	0.07	0.10	0.06	52	17.10	2.77	0.20	1.68 + + -
FORTLEZA	2006	1.03	-0.20	0.11	0.07	0.09	0.04	59	14.91	2.25	2.72	1.67 + + +
FORTLEZA	2007	1.28	-0.27	-0.01	0.04	0.07	0.03	72	30.48	3.82	0.32	1.67 + + -
FORTLEZA	2008	1.16	-0.48	0.08	0.07	0.09	0.06	56	16.00	5.22	1.40	1.67 + + -
GILCREEK	1994	-2.07	-0.93	0.25	0.05	0.04	0.05	64	41.44	23.94	5.25	1.67 + + +
GILCREEK	1996	-2.30	-0.67	-0.02	0.07	0.06	0.07	66	34.02	11.51	0.30	1.67 + + -
GILCREEK	1997	-2.12	-0.76	0.17	0.07	0.04	0.07	59	29.65	17.53	2.42	1.67 + + +
GILCREEK	1998	-2.02	-0.93	0.16	0.06	0.04	0.05	75	34.69	23.51	3.22	1.67 + + +
GILCREEK	1999	-1.83	-0.80	0.36	0.09	0.05	0.06	59	20.71	17.29	5.57	1.67 + + +
GILCREEK	2001	-2.08	-0.78	0.25	0.08	0.05	0.08	63	26.65	16.79	3.13	1.67 + + +
GILCREEK	2002	-5.42	0.94	1.28	0.45	0.18	0.13	101	12.00	5.11	9.78	1.66 + + +
GILCREEK	2002	-2.57	-0.72	-0.03	0.02	0.01	0.02	99	130.21	57.37	1.27	1.66 + + -
GILCREEK	2003	-2.13	-0.72	0.24	0.05	0.05	0.06	82	41.25	15.20	4.04	1.66 + + +
GILCREEK	2005	-2.39	-0.86	0.15	0.04	0.03	0.04	96	62.91	29.70	3.43	1.66 + + +
KOKEE	1994	3.21	-6.29	-0.02	0.04	0.04	0.04	52	41.31	145.14	0.33	1.68 + + -
KOKEE	1995	3.30	-6.46	0.03	0.05	0.07	0.07	61	62.26	87.69	0.43	1.67 + + -
KOKEE	1996	3.08	-5.95	-0.21	0.08	0.10	0.07	90	39.33	59.24	3.04	1.66 + + +
KOKEE	1997	3.04	-6.17	-0.21	0.00	0.09	0.10	62	27.77	70.19	0.12	1.67 + + -
KOKEE	1998	3.15	-5.95	-0.20	0.06	0.07	0.05	70	48.55	81.61	3.92	1.67 + + +
KOKEE	1999	3.36	-6.17	-0.20	0.09	0.09	0.08	79	35.69	68.45	1.91	1.66 + + +
KOKEE	2000	3.28	-6.36	0.02	0.00	0.03	0.00	57	16.16	55.90	0.13	1.67 + + -
KOKEE	2000	3.25	-6.24	-0.14	0.06	0.05	0.05	89	52.60	137.26	2.63	1.66 + + +
KOKEE	2001	3.19	-6.24	-0.05	0.07	0.03	0.05	79	44.27	179.32	1.01	1.66 + + -
KOKEE	2002	3.44	-6.32	-0.06	0.08	0.04	0.06	78	40.87	141.07	1.08	1.67 + + -
KOKEE	2003	3.27	-6.29	-0.04	0.00	0.04	0.10	62	22.80	79.71	0.38	1.67 + + -
KOKEE	2004	3.43	-6.22	-0.10	0.06	0.05	0.04	95	53.16	121.40	2.52	1.66 + + +
KOKEE	2005	3.61	-6.19	-0.10	0.08	0.05	0.04	79	26.97	74.77	1.77	1.66 + + +
KOKEE	2008	3.51	-6.35	-0.09	0.06	0.05	0.05	92	63.36	137.82	1.79	1.66 + + +
KOKEE	2007	3.29	-6.28	-0.20	0.08	0.05	0.05	86	42.58	104.90	3.85	1.66 + + +
MATERA	2008	1 79	2.26	-0.20	0.08	0.00	0.05	62	40.31	74.56	3.67	1.60 + + +
MATERA	2003	1.81	2.36	-0.11	0.04	0.02	0.02	68		120.29	6.41	1.67 + + +
NYALES20	2001	1.54	1.03	0.78	0.04	0.02	0.07	74	42.97	44.64	11.63	1.67 + + +
NYALES20	2002	1.54	1.00	0.70	0.01	0.01	0.04	93	103.10	79.07	17.66	1.66 + + +
NYALES20	2003	1.46	1.14	0.88	0.02	0.02	0.07	58	65.73	72.95	12.77	1.67 + + +
NYALES20	2004	1.52	1.04	0.85	0.04	0.02	0.11	60	42.64	48.41	8.07	1.67 + + +
NYALES20	2005	1.54	1.16	0.87	0.03	0.01	0.07	79		102.45	13.26	1.66 + + +
NYALES20	2006	1.59	1.06	0.76	0.04	0.03	0.08	52	39.11	40.52	10.10	1.68 + + +
NYALES20	2007	1.50	1.11	0.70	0.04	0.02	0.08	53	41.64	66.67	8.82	1.68 + + +
NYALES20	2008	1.36	1.19	0.35	0.06	0.05	0.15	56	24.77	25.52	2.37	1.67 + + +
SVETLOE	2005	0.94	2.02	0.07	0.07	0.05	0.06	51	13.17	39.51	1.24	1.68 + + -
TIGOCONC	2003	1.76	3.16	0.21	0.09	0.05	0.05	82	19.56	61.73	4.16	1.66 + + +
TIGOCONC	2004	1.98	3.46	-0.10	0.16	0.07	0.09	58	12.33	46.30	1.04	1.67 + + -
TIGOCONC	2005	2.13	3.57	-0.46	0.14	0.06	0.07	92	15.69	60.37	6.95	1.66 + + +
TIGOCONC	2006	1.91	3.54	-0.20	0.06	0.04	0.03	91	34.23	91.25	6.02	1.66 + + +
TIGOCONC	2007	1.80	3.36	-0.13	0.07	0.05	0.03	90	24.25	66.88	4.09	1.66 + + +
TIGOCONC	2008	1.47	3.43	-0.14	0.12	0.10	0.08	67	12.51	35.46	1.80	1.67 + + +
WESTFORD	2000	0.19	-1.57	-0.03	0.06	0.06	0.00	52	3.43	24.26	0.70	1.68 + + -
WESTFORD	2001	0.13	-1.59	-0.06	0.03	0.02	0.04	74	7.29	96.46	5.46	1.67 + + +
WESTFORD	2002	0.24	-1.53	-0.03	0.05	0.02	0.02	65	7.78	64.60	2.19	1.67 + + +
WESTFORD	2003	0.33	-1.55	-0.04	0.05	0.02	0.02	59	6.09	49.66	2.19	1.67 + + +
WESTFORD	2004	0.27	-1.51	0.06	0.04	0.05	0.03	63	2.87	31.40	1.91	1.67 + + +
WESTFORD	2005	0.19	-1.59	-0.04	0.08	0.03	0.03	55	2.69	36.68	1.09	
WESTFORD	2000	0.22	-1.58	-0.04	0.00	0.04	0.05	55	2.09	30.00	1.09	1.67 + + -

In total, 17 radio telescope sites which have consistently taken part in most of the sessions from the beginning of 1994 to end of 2008 are included in our study. In Figure 1, the 17 VLBI sites that participated in the IVS-R1 and IVS-R4 24 hour (daily) sessions are shown. Figure 2 shows north, east and up components of the yearly site velocities and respective years are plotted.

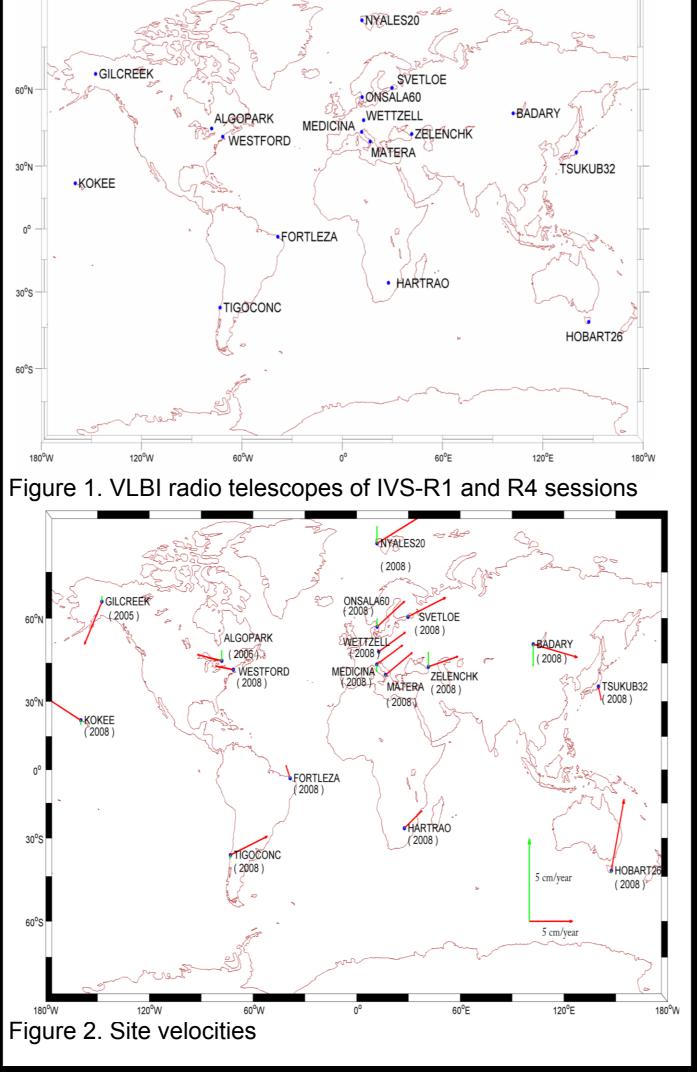
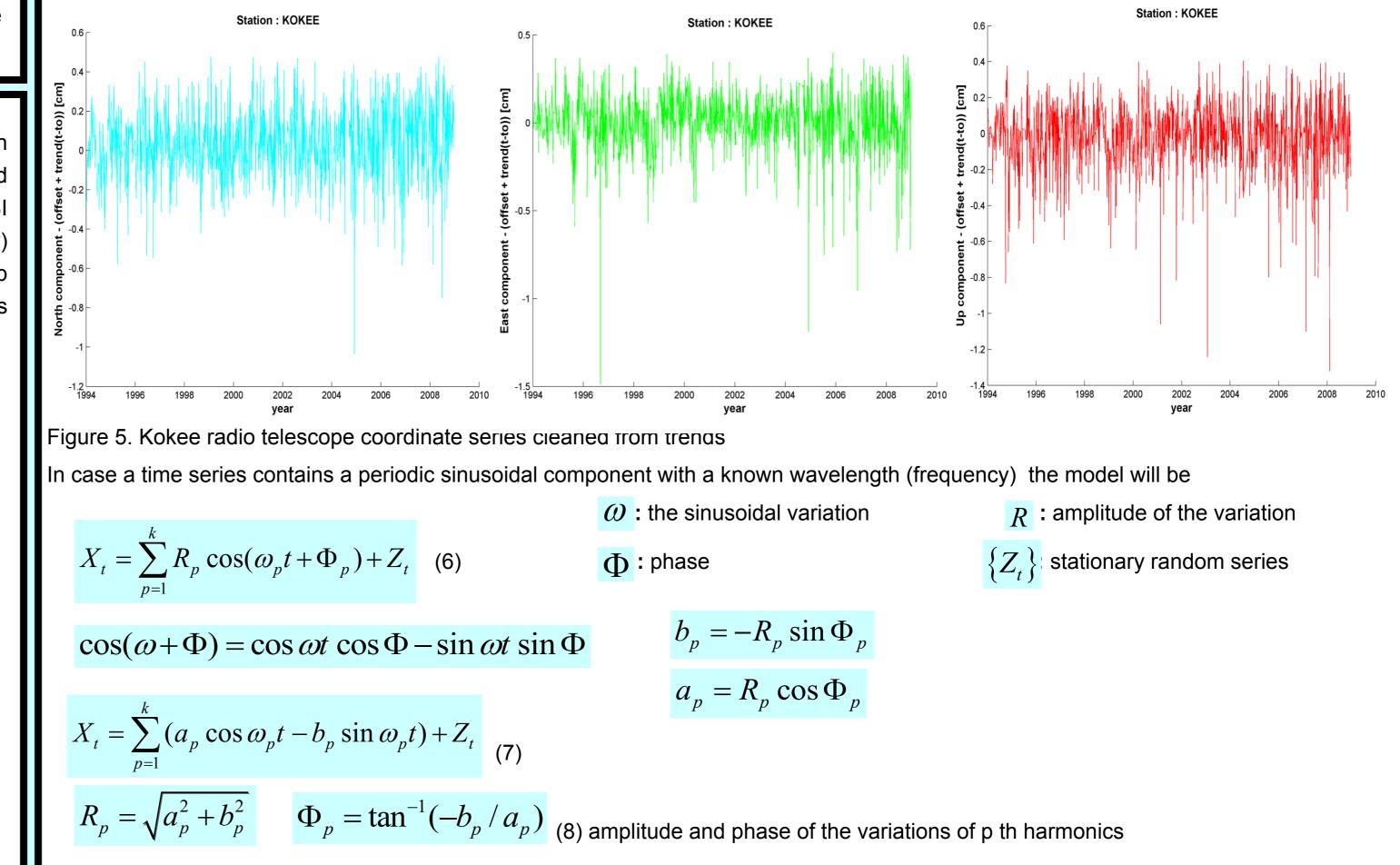
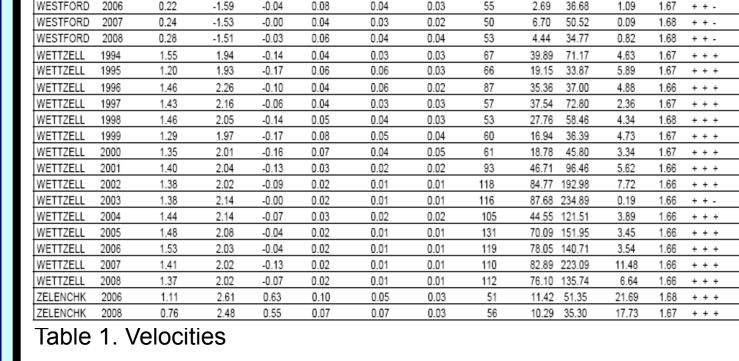


Figure 5. Time series of local topocentric coordinates of the site Svetloe

TIME SERIES ANALYSIS OF COORDINATES: After reduction linear trend the resulted stationary series are analysed by means of detecting harmonics. This single spectral analysis approach known as auto spectral analysis based on the detection of the maximum power and respective frequency. The procedure is carried out iteratively eliminating the maximum amplitude up to reaching noise floor (Schuh, 1981).



If we are interested in variation at low frequency of 1 cycle per year, then we should at least 1 year's data in which case the lowest (fundamental) frequency we can fit is at 1 cycle per year. In other words, the lowest frequency covers the longest time period over the data. The lowest frequency depends on *N* which is the total number of the pairs of amplitudes of the harmonic analysis. The Nyquist frequency is the highest angular frequency (π) about which we can get meaningful information from a set of data. The Fourier series representation of the data is normally evaluated at the frequencies ($2\pi/N$) of provided from the fundamental ($\omega_p = 2\pi p/N$) frequency by multiplying the integers, p = 1, ..., N/2 called as Harmonics (Chatfield, 2004).

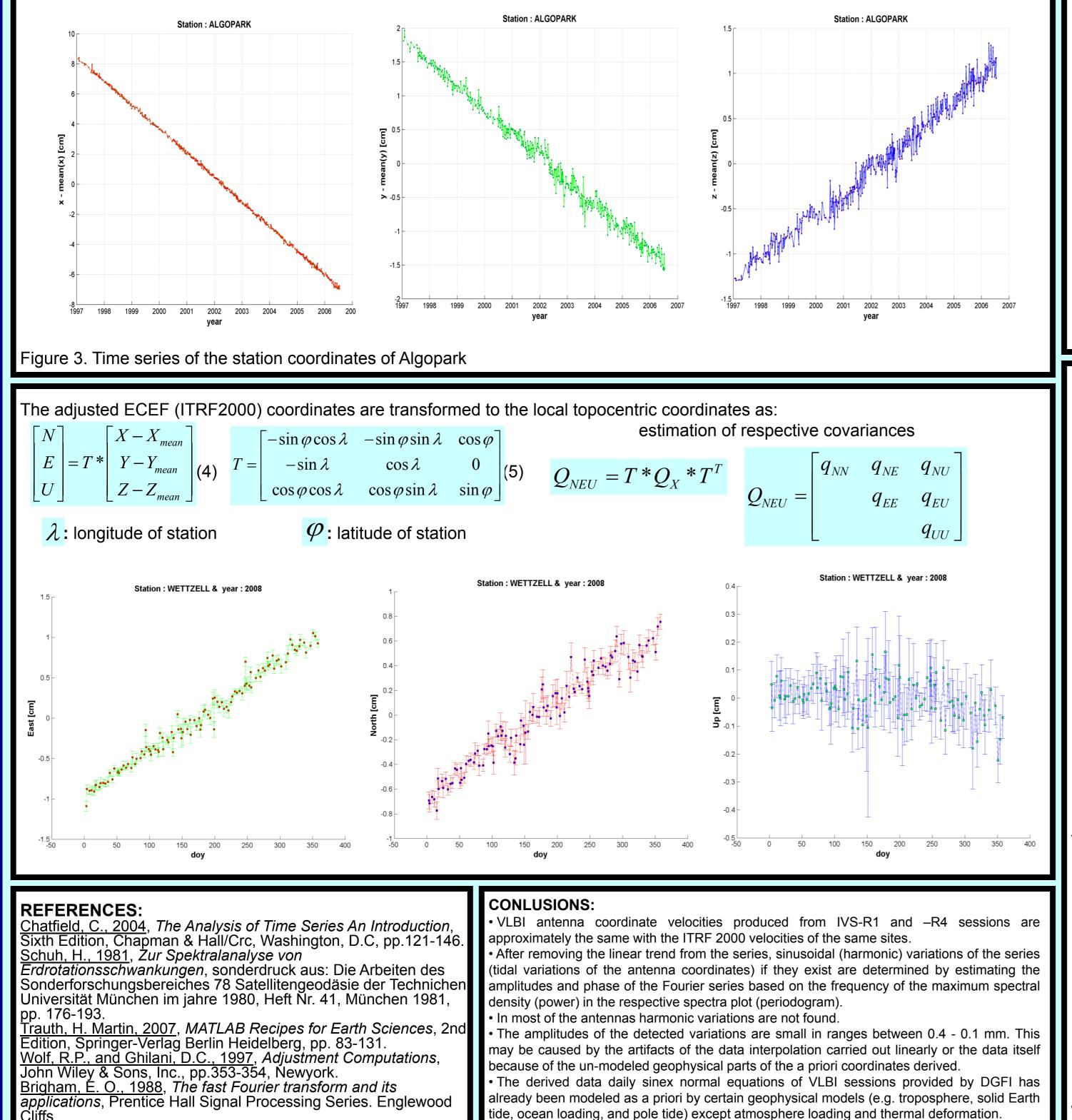


The velocities estimated in this study are almost equal to the ITRF 2005. Table 2 shows the north, east and up components of the some antenna velocities of ITRF 2000 at epoch 1997.0.

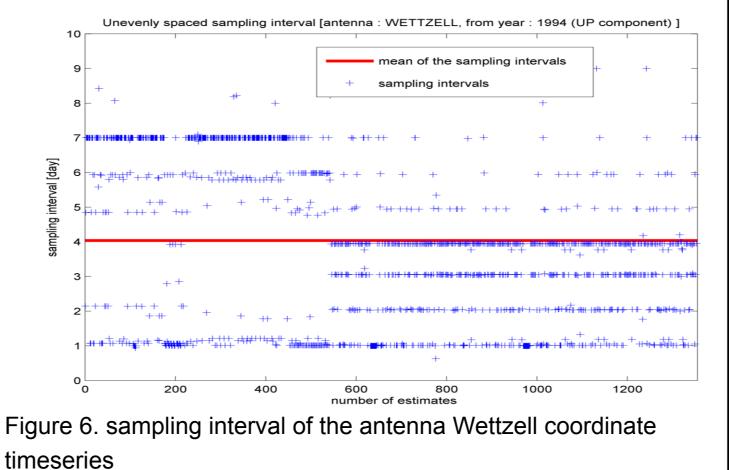
	ITRF 2	000 at epoch	1997.0	from IVS-R1 and -R4 sessions				
Site name	v _{north} [cm]	v _{east} [cm]	<i>v_{up}</i> [cm]	v _{north} [cm] (year)	v _{east} [cm] (year)	<i>v_{up}</i> [cm] (year)		
Algopark	0.13	-1.66	0.23	0.17 (2005)	-1.61 (2005)	0.23 (2002)		
Fortaleza	1.21	-0.43	0.09	1.16 (2008)	-0.48 (2008)	0.11 (2006)		
Kokee	3.24	-6.24	-0.08	3.29 (2008)	-6.46 (1995)	-0.09 (2007)		
Matera	1.81	2.37	-0.10	1.81 (2003)	2.36 (2003)	-0.11 (2003)		
Wettzell	1.44	2.03	-0.09	1.37 (2008)	2.02 (2008)	-0.07 (2008)		

Table 2. Comparison between ITRF2000 and estimated velocity vectors

The Earth Centred Earth Fixed (ECEF) coordinates of the radio telescopes are estimated with minimum constrained Least Squares adjustment from the daily sinex normal equations of VLBI sessions provided by Deutsches Geodatisches Forschungsinstitut (DGFI). The respective a priori station coordinates are computed from the coordinates of 25 globally distributed stations constrained to have NNR and NNT w.r.t. ITRF2000.



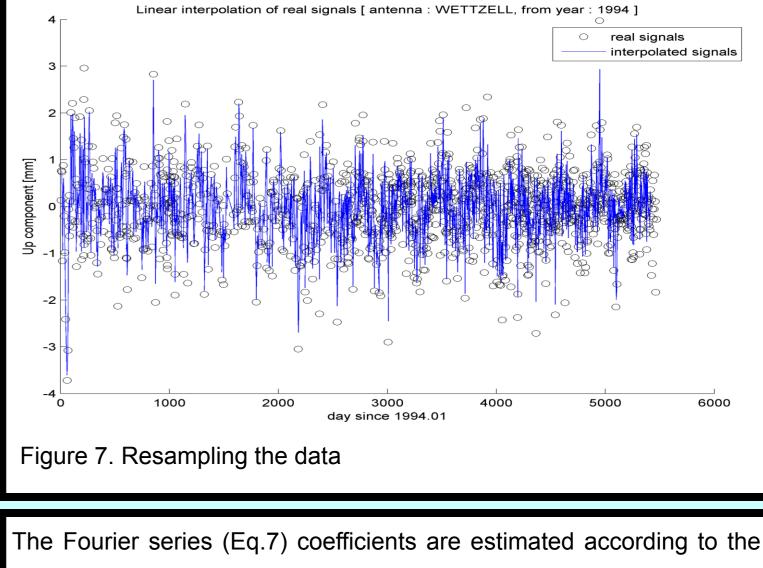
The coordinate time series of the VLBI antennas produced from the daily sinex normal equations of IVS-R1and -R4 sessions are unevenly spaced. As an example, sampling intervals are shown in Figure 6 for the antenna Wettzell. The mean of the sampling interval (e.g. antenna Wettzell up component 4 days) is used for producing the fundamental frequency (the maximum frequency data can produce).



The power spectral density of the time series is computed by Fast Fourier Transform (Brigham, 1988) and ploted in Figure 8.

Autospectrum (Periodogram)

X: 360.8 Y: 325.1 To form evenly spaced data linear interpolation (Trauth, 2007) is applied depending on the evenly-spaced (mean of the sampling interval) time axis (Figure 7). For the unevenly spaced data it seems to be impossible to prevent artifacts and spurious cycyles on the results to some extend since it is not possible to stay with in the range of the original data with any interpolation method..



The Fourier series (Eq.7) coefficients are estimated according to the period (360.8 days (fs = 0.00277)) of maximum power with least squares. With the coefficients of the Fourier Series amplitude and phase of the maximum cyclic variation is provided (Eq.8). The amplitude and phase are found out 0.35 mm and -45.21°, respectively for the Wettzell up component. The Fourier series and the signal is shown in Figure 9.

