DORIS PILOT EXPERIMENT

Report on the

2002 IDS Campaign

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Introduction

The DORIS Pilot Experiment was the preparatory phase of the International DORIS Service (IDS) that was later created by the International Association of geodesy (IAG). In this context, the DORIS Pilot Experiment Central Bureau initiated in November 2001 an Analysis Campaign that focused on time series of station coordinates derived from DORIS observations of the Spot2, Spot4 and Topex/Poseidon satellites. We present hereafter the analysis of the data collected for this campaign. The global combination to define a DORIS technique product was not applied mainly because the number of ACs is not yet large enough.

Participation

Five Analysis Centers (AC) have submitted solutions for the 2002 Analysis Campaign, listed in Table 1. Some iterations have occurred on the deliveries. During the Marne la Vallée IDS workshop in February 2003 the structure and contents of the Sinex files as well as the organization of the Data Centers were detailed. Two AC (IGN-JPL, LEGOS-CLS) have provided time series solutions with full co-variance matrix over the whole 1993-2002 period of DORIS data.

The data were collected under the form of Sinex files (IERS 2003), which include in principle the full variance-covariance information related to the estimated parameters, here the sets of station coordinates. The list and content of the submitted Sinex files is detailed in table 2. All of the series (except ones from SOD/CNES) are available in the Data Centers on the repertories doris/products/sinex_series and on the corresponding sub-directories: ignmd, lcamd, inamd for the monthy solutions, respectively ignwd, lcawd, inawd, ssawd for the weekly solutions. Three days SOD/CNES (STA3j_) solutions were experimental. They had not been aligned to the Sinex naming convention. They are named STA3j_jjcnes where jjcnes is the conventional CNES julian day (18628 for 01/01/2001).

Sinex naming and content are described at http://lareg.ensg.ign.fr/IDS/doc/struct_dc.html.

Table 1. Participating analysis centers

Analysis Center (AC)	AC abbrev.	Team-Contact	Description	Data span	Constraints
Campaign solutions					
IGN-JPL (France-USA)	ign	P. Willis Y Bar-Sever	Spot2/3/4 & Topex Monthly & weekly solutions	1993-2002	Loose (100m) proj. rotations
LEGOS/CLS (France)	lca	J.F. Crétaux L. Soudarin	Spot2/3/4 & Topex Monthly solutions	1993-2002	Loose (1m)
INASAN (Russia)	ina	S. Tatevian S. Kuzin	Spot2/3/4 & Topex Monthly & weekly solutions	1999-2002	Loose
Operationnal solutions					
SOD/CNES (France)	sod	A. Guitart J.P. Berthias	Spot2/4/5 & Topex 3 days solutions	2002	Loose
SSALTO CNES-CLS (France)	ssa	J.J. Valette G. Tavernier	Spot2/4 & Topex Spot5 (05/02>) weekly solutions	2001-2003	Unremovable (Fixed orbit)

Table 2. Contents of the collected Sinex files

AC	Series (*)	data span	Number of solutions	Contents	Characteristics
ign	md03 wd03	1993-2002 1993-2002	118 522	XYZ stations & EOP	Gipsy-Oasis software Free-network All series projected and transformed only in rotation into ITRF2000 (without worst DORIS stations)
ina	md01 wd01	1999-2002 1999	36 37	XYZ stations & EOP	Gipsy-Oasis software Free-network All series projected and transformed only in rotation into ITRF2000
lca	md02	1993-2002	108	XYZ stations & EOP	GINS/Dynamo software 1 m loose constraints no projection, no transformation
sod	STA3j_	09-2002 to 01-2003	99	XYZ stations & EOP	ZOOM software Loose constraint
ssa	wd01	2001-2003	119	XYZ stations	SSALTO localisation software MOE fixed orbits from CNES (MOE: Medium Ephemerides)

* Series description: tdvv
t for solution type with m for monthly solutions and w for weekly solutions
d for DORIS
vv for the version

Analysis strategy

The analysis of station positions is done using the common Helmert similarity of seven transformation parameters. Sinex files with full covariance matrices are checked and then combined with estimation of variance factors. A recommendation was done to the analysts to provide loose constraint solutions (sigma > 1 m on the station coordinates) or minimal constraint solutions.

The call for participation requested that one of the following three forms of constraints be used:

- Loose constraints: solutions where the uncertainty applied to the constraints is greater than 1 m for positions and greater than 10 cm/year for velocities. The constraint matrix in the Sinex block should be coded "SOLUTION/APRIORI".
- Removable constraints: solutions for which the estimated station positions and/or velocities are constrained to external values within an uncertainty around 10^{-5} m for positions and 10^{-6} m/year for velocities. In this case, the constraint matrix in the Sinex block should be coded "SOLUTION/APRIORI".
- Minimum constraints used solely to define the Terrestrial Reference Frame using a minimum amount of required information. For more details on the concepts and practical use of minimum constraints (see for instance Altamimi et al, 2001). The Analysis Center is invited to give details of how the method has been applied.

The analysis is based on the IGN/LAREG CATREF software (Altamimi et al, 2002), whose analysis structure is outlined in figure 1. For each monthly or weekly time series of stations positions of a given Analysis Center, we have run CATREF in a global combination to estimate their internal consistency. First step is to remove uncertainties in the coordinate system associated to each solution and to express all of them in the same reference frame (datum definition). This step is done with the application of the minimum constraint equations without disturbing the underlying information. The datum definition makes use of a subset of reliable stations. The list used for this report is given in Annex 1.

The combinations of time series were done Analysis Center by Analysis Center and type by type (monthly/weekly).

CATREF data modeling and analysis

For a given Analysis Center, the input is a time series of station positions and associated variance-covariance matrices: X_s^i, Σ_s^i. The general combination model is based on the following equation:

$$\boxed{X_s^i = X^i + (t_s^i - t_0)\cdot \dot{X}^i + T_k + D_k \cdot X^i + R_k \cdot X^i}$$

where t_s^i is the epoch of station $\boldsymbol{i}$ available in solution $\boldsymbol{s}$ and t_0 is chosen to be the median epoch of the incorporated solutions. T_k, D_k, R_k are estimated translation, scale factor and rotation, where k is the frame associated to the solution **s**. $X^i, \dot{X}^i$: combined solution at t_0.

The normal equation constructed using the above model is singular, having a rank deficiency of 14, corresponding to the datum definition parameters. In order to define the combined frame an equation of minimum constraints is used, given by:

$$(A^T A)^{-1} A^T (X_R - X_E) = 0$$

where $\boldsymbol{X_E}$ is the vector of estimated station positions and velocities, $\boldsymbol{X_R}$ is the reference solution containing a selected set of stations and A is the design matrix of partial derivatives. Unlike the classical constraints applied over station coordinates, minimum constraints are applied over the frame parameters, thus allowing to express the combined solution in any external frame (e.g. ITRF2000), without altering the quality (or internal consistency) of the estimated solution. For more details, see (Altamimi et al., 2002) and (Sillard et al. 2001). The variance analysis is based on a variance factor estimation for each solution after the combination, as specified in (Altamimi et al., 2002).

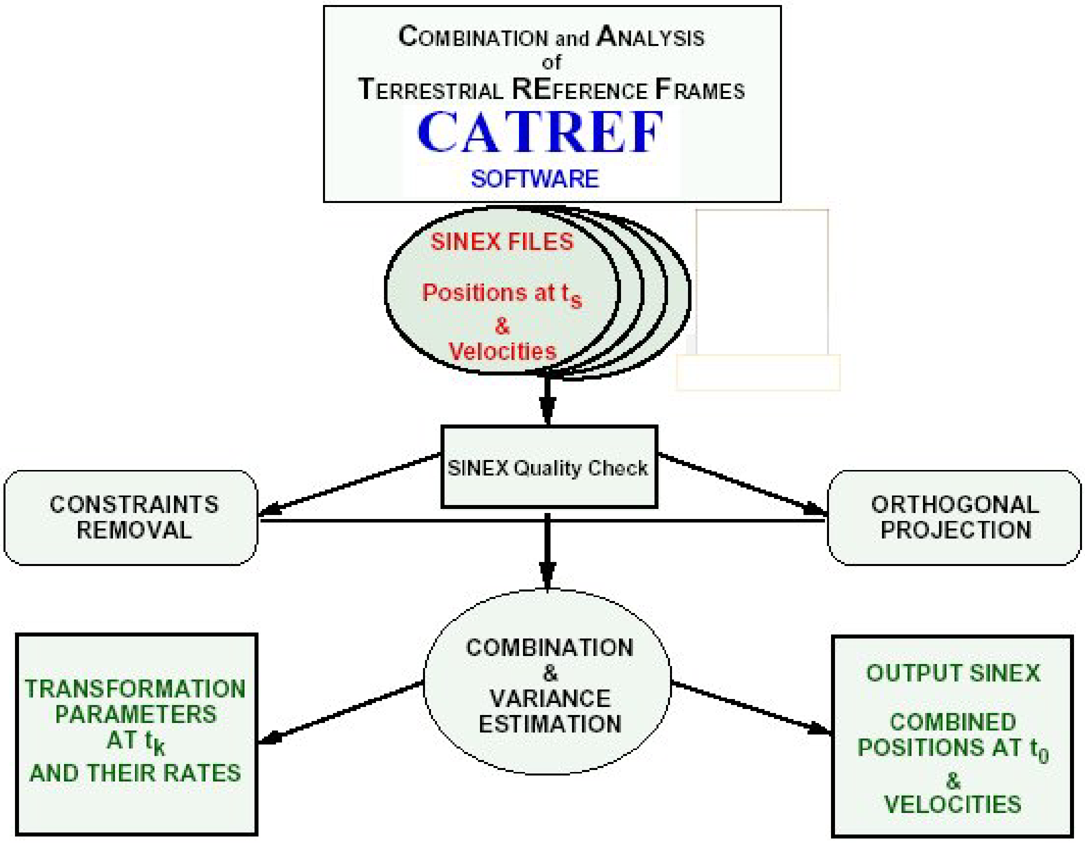

Figure 1. Analysis structure of the CATREF software package

Consistency of individual monthly series

The combination of individual monthly series for each Analysis Center provides the internal consistency of the solutions. Results are analysed in terms of transformation parameters and stations residuals.

Transformation parameters

The monthly solutions in translation and scale factor are plotted in figures 2, 3 and 4 for the ign AC, the lca and ina ACs. A trend, a bias and the standard deviation after removing the trend been calculated for the transformation parameters, listed in table 2.

Table 2. Analysis of the combination of each individual monthly time series

	ign (md03) 1993-2002			**lca (md02) 1993-2002**			**ina (md01) 1999-2002**		
Stations number (mean)	45			48			46		
WRMS (mm) (Mean and Std Dev)	21 ± 8			14 ± 3			17 ± 4		
Translation Parameters	Trend (mm/yr)	Bias (mm)	Std Dev* (mm)	Trend (mm/yr)	Bias (mm)	Std Dev* (mm)	Trend (mm/yr)	Bias (mm)	Std Dev* (mm)
TX	0.0	10.6	6.0	-0.3	-6.0	7.2	-9.9	5.6	6.7
TY	-0.5	-1.1	5.4	-0.6	-5.8	6.0	7.1	-3.5	6.2
TZ	1.9	-7.8	26.0	4.8	21.7	18.6	11.4	100.1	33.1
Scale factor	Trend (ppb/yr)	Bias (ppb)	Std Dev* (ppb)	Trend (ppb/yr)	Bias (ppb)	Std Dev* (ppb)	Trend (ppb/yr)	Bias (ppb)	Std Dev* (ppb)
DD	0.0	-1.8	0.5	-2	0.6	0.5	0.5	-10.4	0.6

* Trend is removed

The figures also show the result of a time series analysis by the Allan variance technique (Allan 1966). The Allan variance of a time series x_i with N items and sampling time τ is defined as:

$$\sigma_A^2(\tau) = \frac{\Sigma_1^N (x_{i+1} - \mathrm{x_i})}{2N}$$

The Allan variance analysis allows one to characterize the power spectrum of the variability in time series, for sampling times ranging from the initial interval of the series to 1/4 to 1/3 of the data span. This method allows one to identify white noise (spectral density S independent of frequency f), flicker noise (S proportional to f^{-1}), and random walk (S proportional to f^{-2}). Note that one can simulate flicker noise in a time series by introducing steps of random amplitudes at random dates. In the case of a white noise spectrum, accumulating observations with time eventually leads to the stabilisation of the mean position. In the case of flicker noise, extending the time span of observation does not improve the quality of the mean coordinates. A convenient and rigorous way to relate the Allan variance of a signal to its error spectrum is the interpretation of the Allan graph, which gives the changes of the Allan variance for increasing values of the sampling time τ. In logarithmic scales, slopes -1, 0 and +1 correspond respectively to white noise, flicker noise and random walk noise.

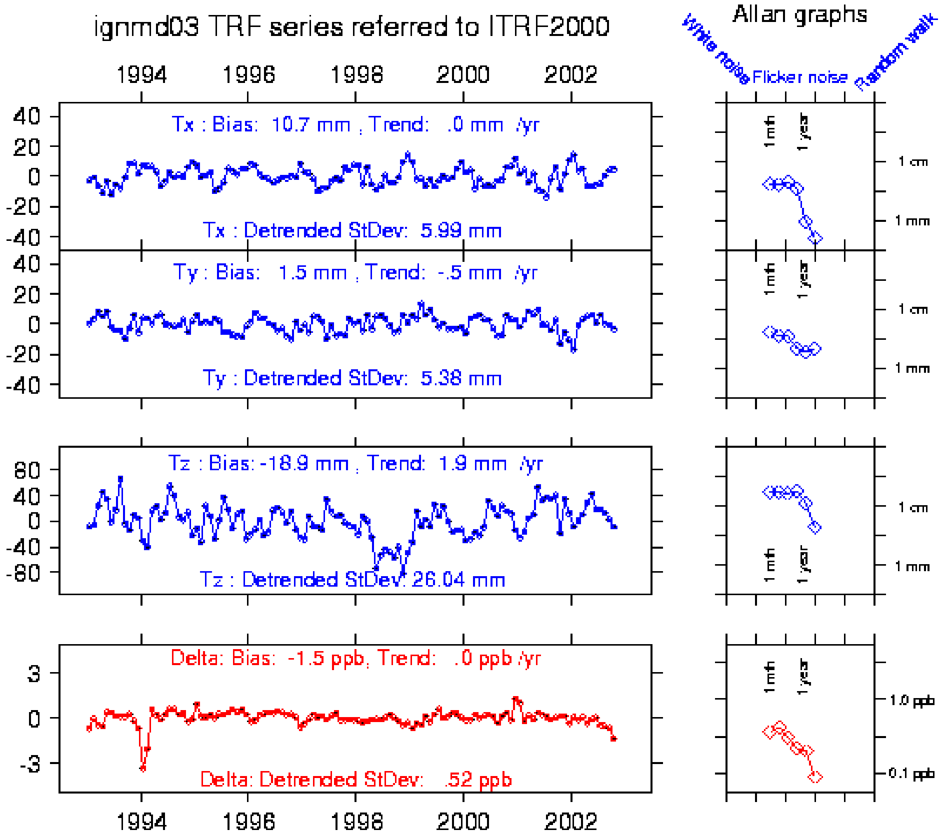

Figure 2. Translation and Scale factor of the monthly solution time series combination. IGN-JPL Analysis Center

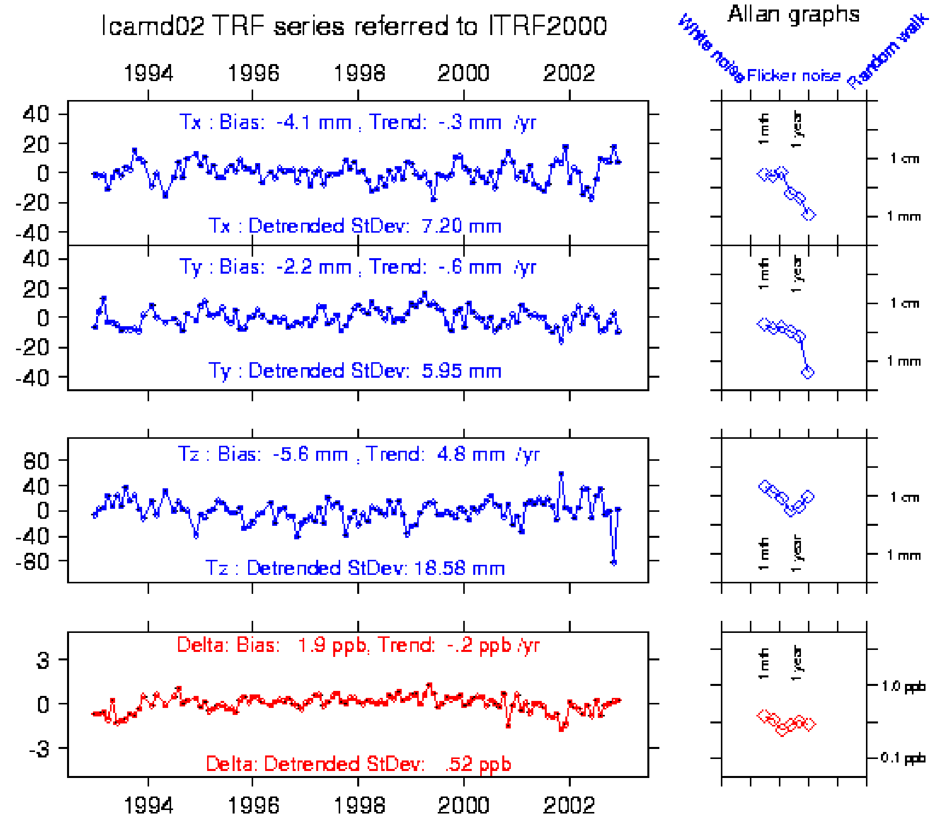

Figure 3. Translation and Scale factor of the monthly solution time series combination. LEGOS/CLS Analysis Center

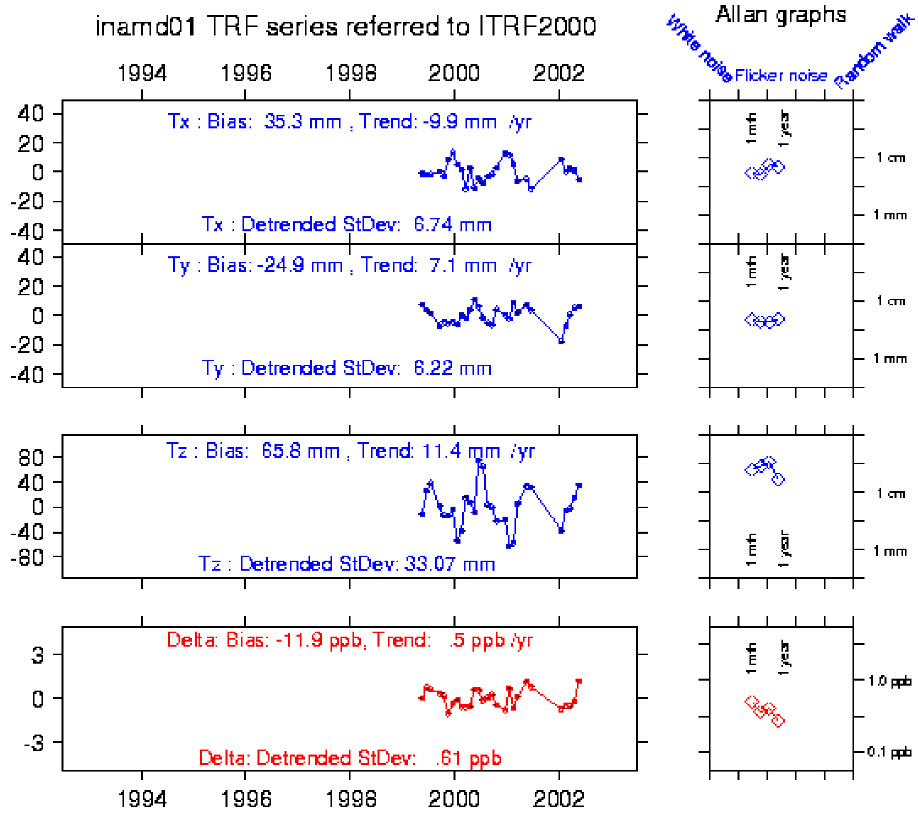

Figure 4. Translation and Scale factor of the monthly solution time series combination. INASAN Analysis Center

Stations residuals

All site-by-site residuals resulting from the individual combination of each AC have been represented on a same plot. See annexes A2.1-2-3 for examples at Easter Island, Fairbanks and Badary. All plots are available in png readable format at ftp://ftp.cls.fr/pub/ids-cls/. Table 3 gives global statistics for these time series. Figures 5 and 6 show the distribution of station residuals globally and per station.

Table 3. Statistics from rms station positions residuals: mean value and standard deviation after individual combination of monthly time series.

	ign (md03) 1993-2002	**lca (md02) 1993-2002**	**ina (md01) 1999-2002**
North (mm)	19 ± 4	17 ± 10	20 ± 5
East (mm)	25 ± 9	25 ± 12	29 ± 10
Up (mm)	19 ± 6	20 ± 10	21 ± 9
3D (mm)	22 ± 6	22 ± 9	24 ± 6

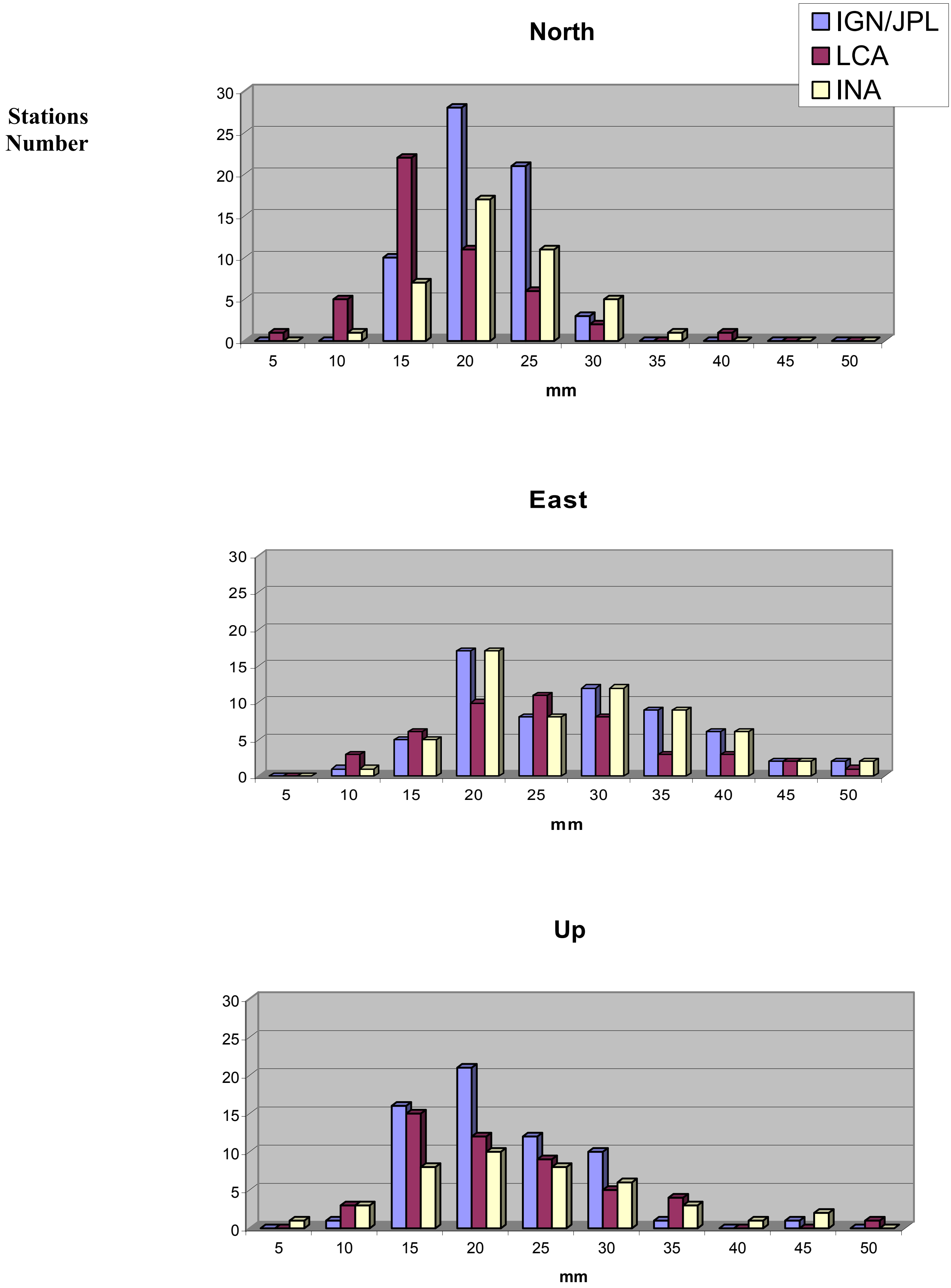

Figure 5. Station residuals distribution (monthly solutions)

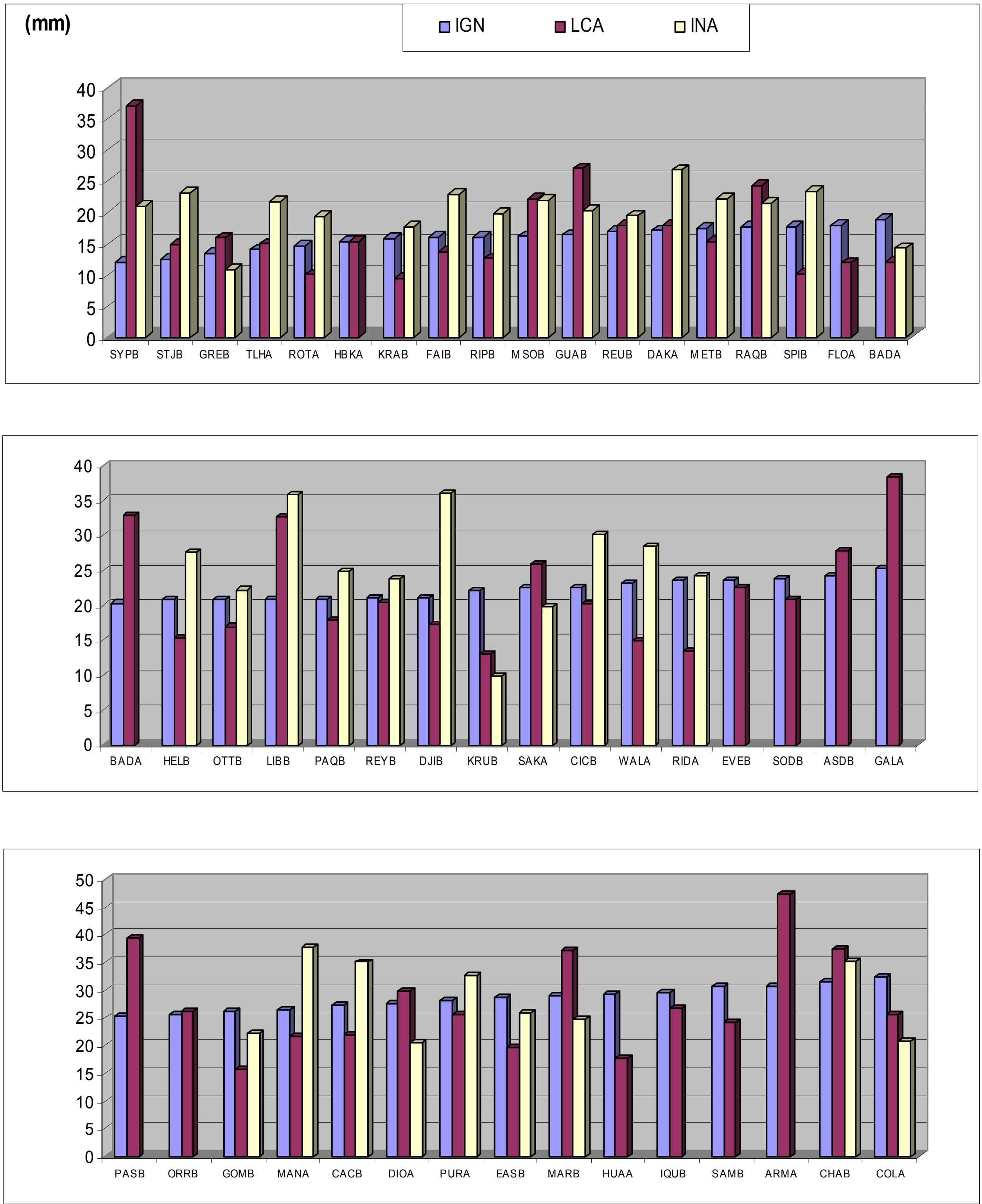

Figure 6. Station by station 3D residuals analysis (monthly solutions)

Outliers

For each combination the outliers at 4, 7 and 10 times the sigma of the normalized station position residuals have been examined. Their statistics are given in table 4. Table 5 lists the 10 sigma outliers.

Table 4. Statistics of monthly solutions over 4, 7 and 10 times sigma.

	ign (md03) 1993-2002		**lca (md02) 1993-2002**		**ina (md01) 1999-2002**	
	Sol. nb	%	Sol. nb	%	Sol. nb	%
4 σ	308	6	896	17	103	6
7 σ	13	0.2	84	1.6	22	1.3
10 σ	3	0.05	22	0.4	7	0.4

Table 5. Stations over 10 times sigma.

ign (md03)			**lca (md02)**			**Ina (md01)**		
Domes	Station	Solution	Domes	Station	Solution	Domes	Station	Solution
22006S001	MANA	ign00121md	12334S005	KITB	LCA96183	10202S002	REYB	ina00032
40102S009	OTTA	ign97274md	12334S005	KITB	LCA97001	30606S003	HELB	ina99182
41609S001	CACB	ign02213md	12334S005	KITB	LCA97032	40424S008	KOKA	ina00032
			12334S005	KITB	LCA97060	42004S001	GALA	ina00032
			21604S003	PURA	LCA00032	50207S001	CHAB	ina00032
			21604S003	PURA	LCA00061	92201S008	PAQB	ina00032
			23501S001	COLA	LCA94305	92901S001	WALA	ina00032
			30302S202	HBKA	LCA96245			
			32809S003	LIBB	LCA01335			
			40408S004	FAIA	LCA96336			
			40503S003	SODA	LCA93001			
			40503S003	SODA	LCA93060			
			40503S003	SODA	LCA97182			
			42202S005	AREA	LCA01152			
			50207S001	CHAB	LCA00032			
			50207S001	CHAB	LCA00122			
			66006S003	SYPB	LCA01305			
			66006S003	SYPB	LCA01335			
			66007S001	ROTA	LCA94060			
			91201S003	KERB	LCA97032			
			91501S001	ADEA	LCA01305			
			92201S008	PAQB	LCA00153			

Breaks in station coordinates time series

The changes and controlled events that occurred in the DORIS stations network are listed at http://lareg.ensg.ign.fr/IDS/doc/sta_parsta.html

Some anomalies due to geophysical sources (earthquake, volcanic eruption…), equipment, erosion or uncontroled human intervention have been identified:

OTTA: Ottawa: several points have been defined for the same antenna using information contained in the DORISMail #0062 jan 4, 1999
AREA: Arequipa: A second point has been defined after the 2001, June Earthquake.
COLA: Colombo: A second point has been defined after November 1994
DIOA: Dyonisos: A second point has been defined after April 1, 1995
SAKA: Sakhalin: A second point has been defined after Oct 5, 1994 (earthquake on Oct 4, 1994)
SAKA: Sakhalin: A thhird point has been defined after Dec 26, 1999
KRAB: Krasnoyarsk: A second point has been defined after Nov 1999
SODB: Soccorro Is.: A second point has been defined after Oct 3, 2002 (earthquake on Oct 3, 2002)
AMSA: all data have been deleted after Jan 1, 1996 (antenna fall)
AMSB: Amsterdam all data have been deleted (antenna fall)
SODA: All data have been deleted before Jan 1, 1996 (volcano depletion)

(Source: P. Willis ignmd03.dsc Sinex description files).

Products

The individual monthly solutions combination of the three AC leads to three global sinex solutions in positions and velocities.

There are named:
Camp02-ign03d03.snx.Z
Camp02-lca03d02.snx.Z
Camp02-ina03d01.snx.Z

They available at ftp://ftp.cls.fr/pub/ids-cls/ (anonymous). Directory is camp2002/month_analysis.

Consistency of individual weekly series

The combination of individual weekly (or three days from sod AC) series for each Analysis Center provides the internal consistency of such solutions. Results are analysed in terms of transformation parameters and stations residuals.

Transformation parameters

The translation and scale factor parameters and their Allan variance graphs are plotted in figures 7, 8 and 9, respectively for the ign, ssa and sod ACs. Table 6 gives their mean value and standard deviation.

Table 6. Mean values and standard deviations of the transformation parameters after individual combination of monthly time series.

	IGN (wd03) 1993-2002	**SSA (wd01) 2001-2003**	**SOD (STA3j_) 1999-2002 (3 days)**
Number of stations (mean)	43	45	46
WRMS (mm)	34 ± 11	33 ± 8	40 ± 17
TX(mm)	10 ± 8	-56 ± 25	10 ± 11
TY(mm)	2 ± 8	25 ± 14	22 ± 11
TZ(mm)	-15 ± 35	-38 ± 22	-55 ± 18
Scale (10^{-8})	-16 ± 6	-1 ± 16	-3 ± 5

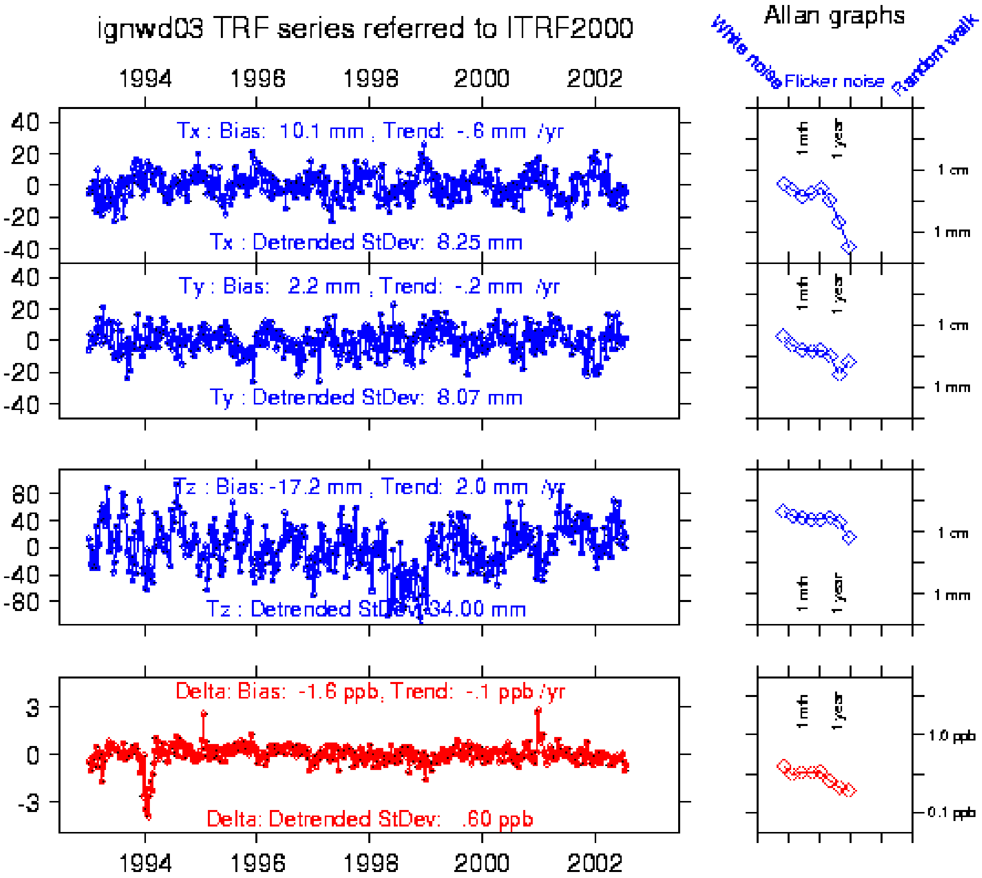

Figure 7. Translation and Scale factor of the weekly solution time series combination. IGN-JPL Analysis Center

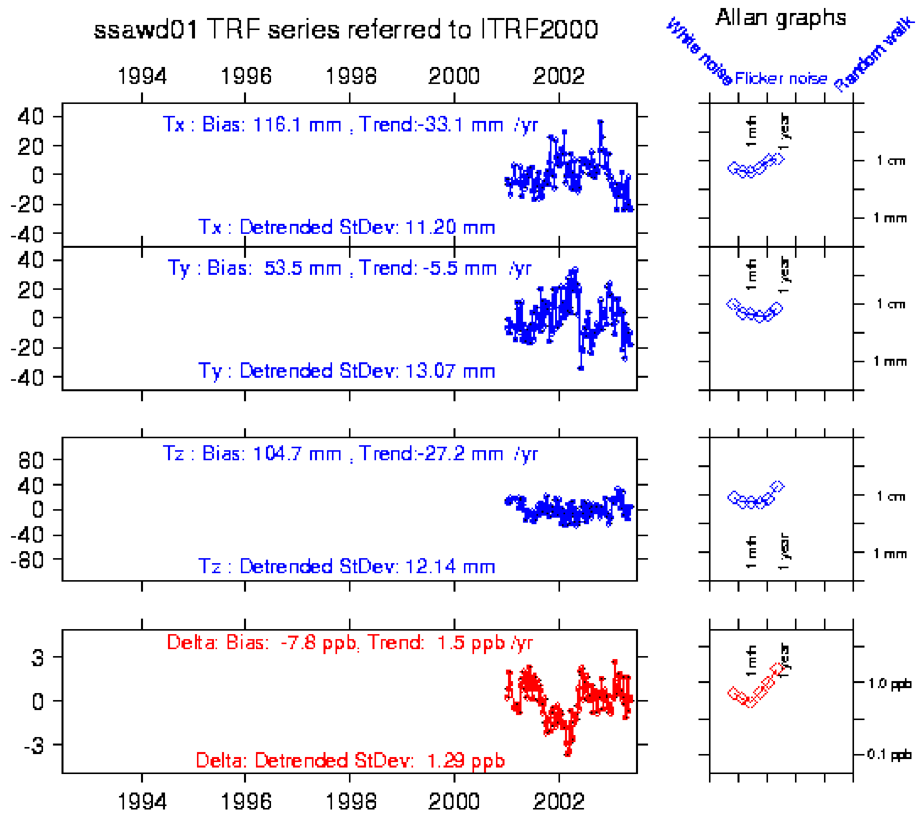

Figure 8. Translation and Scale factor of the weekly solution time series combination. SSALTO Analysis Center

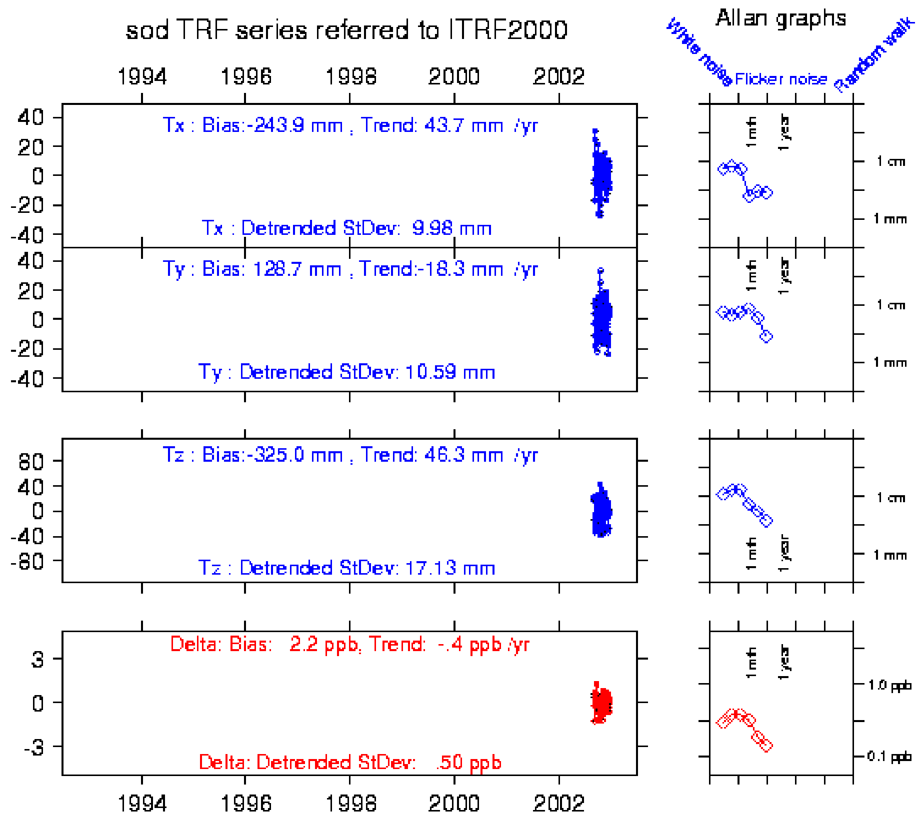

Figure 9. Translation and Scale factor of the 3-day solution time series combination. SOD Analysis Center

Stations residuals

Table 7 gives global statistics for the weekly and 3-day time series.

Table 7. Statistics from rms station positions residuals: mean value and standard deviation after individual combination of weekly series (except sod: 3 days).

	ign (wd03) **1993-2002**	**ssa (wd01)** **2001-2003**	**sod (STA3j_)** **1999-2002**
Solution number	522	120	99
Stations number	45	38	41
Outliers **(not used)**	Floa Raqb Guab Krub Helb Libb Gala Arma Waia Iqub Hvoa Carb	-	Cacb, Asdb, Djib
North (mm)	54 ± 13	31 ± 7	48 ± 10
East (mm)	54 ± 13	40 ± 14	61 ± 18
Up (mm)	35 ± 10	33 ± 14	33 ± 6
3D (mm)	49 ± 13	36 ± 9	49 ± 10

Conclusions

The main purpose of this analysis campaign was to initiate analysis coordination activities within the DORIS Pilot experiment, to prepare a more permanent action in the framework the IDS. The IDS was created in July 2003 by the IAG. The analysis coordination activities are jointly performed by the Analysis Coordinator and the Central Bureau. Discussion among the IDS analysts is also continued through workshops (see for example http://lareg.ensg.ign.fr/IDS/events/prog_2003.html) and new analysis campaigns. See http://lareg.ensg.ign.fr/IDS/ for the monitoring of IDS analyses.

This report provides a first example of what can be provided to the Analysis Centers in terms of data analyses. Further improvements in this domain include, e.g., the detailed consideration of breaks of all origins in the stations operations, taking account of the estimations of the Earth's pole coordinates, and combination of several Analysis Centers solutions. The IDS Analysis Centers are welcome to discuss this report and to suggest improvements to the analyses provided.

References

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Annexes

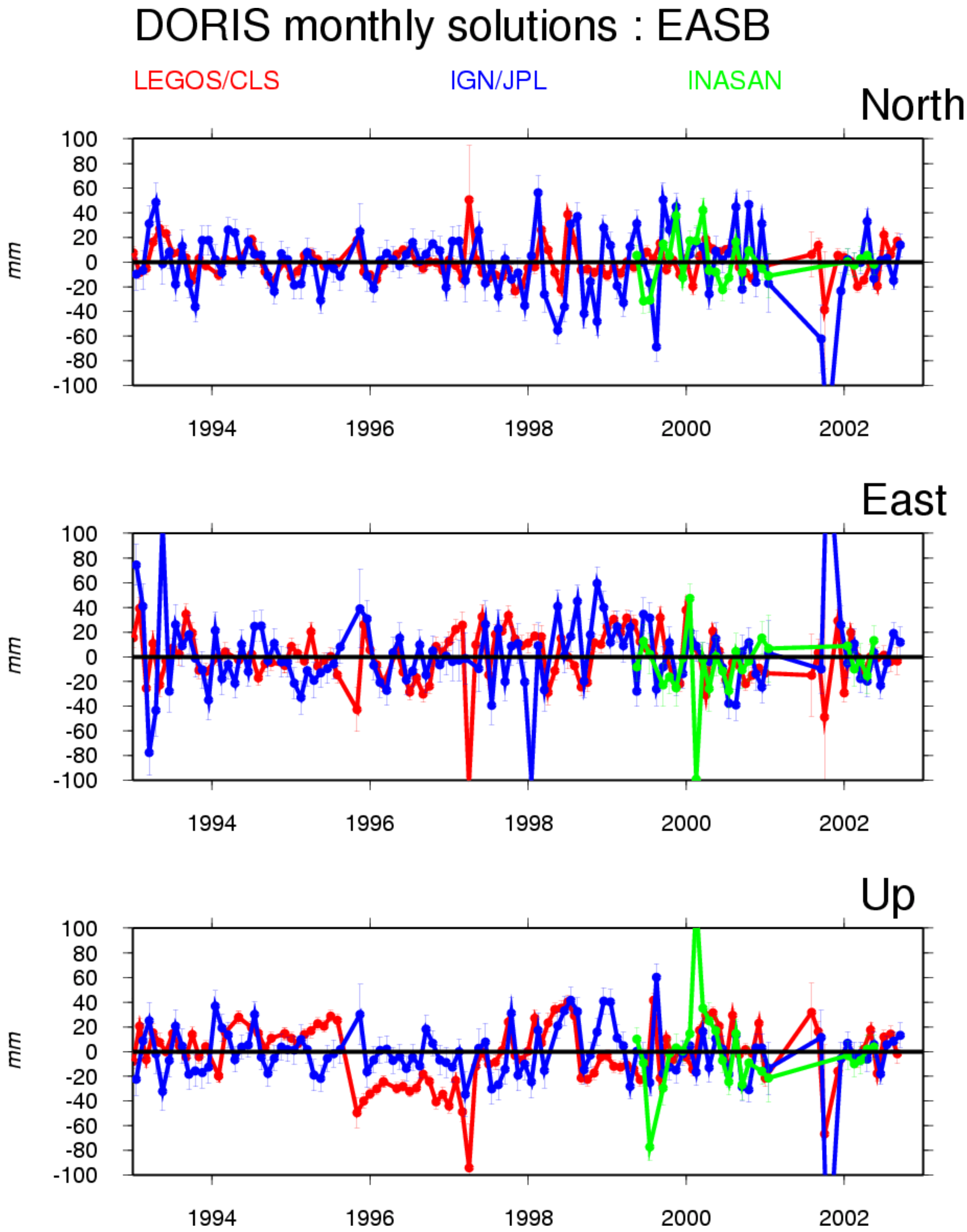
A1 – Datum definition

ITRF2000 sub-network: best DORIS stations also included in the time series

*CODE	PT	__DOMES__	T	_STATION DESCRIPTION__	APPROX_LON_	APPROX_LAT_	_APP_H_
ADEA	A	91501S001		ILE DES PETRELS antenn	140 00 05.1	-66 39 45.6	0.9
AREA	A	42202S005		AREQUIPA antenna	288 30 24.9	-16 27 56.6	2493.7
BADA	A	12338S001		BADARY antenna	102 14 05.7	51 46 11.0	812.3
CACB	A	41609S001		CACHOIERA PAULISTA ant	314 59 52.8	-22 40 57.8	571.1
CIBB	A	23101S001		CIBINONG antenna	106 50 55.8	-6 29 26.4	161.1
COLA	A	23501S001		COLOMBO	79 52 27.0	6 53 31.4	-76.8
DAKA	A	34101S004		DAKAR antenna	342 33 59.9	14 43 54.9	44.6
DIOA	A	12602S011		DIONYSOS antenna	23 55 58.3	38 04 42.2	513.6
DJIA	A	39901S002		DJIBOUTI antenna	42 50 47.9	11 31 34.7	716.0
EASA	A	41703S008		EASTER ISLAND antenna	250 36 58.8	-27 08 52.2	120.1
EVEB	A	21501S001		EVEREST antenna	86 48 47.3	27 57 29.3	4962.0
GALA	Z	42004S001		SAN CRISTOBAL antenna	270 23 01.6	-0 54 02.5	5.3
GOMB	A	40405S037		GOLDSTONE antenna	243 12 29.1	35 14 54.1	1041.1
GUAB	A	50501S001		GUAM antenna	144 54 50.4	13 32 23.0	290.9
KERB	A	91201S003		KERGUELEN antenna	70 15 45.7	-49 21 07.5	62.6
KOKA	A	40424S008		KAUAI antenna	200 20 04.7	22 07 23.2	1165.7
KRUB	A	97301S004		KOUROU antenna	307 21 36.7	5 05 55.0	109.8
MANA	A	22006S001		MANILLE antenna	121 02 28.2	14 32 07.6	87.0
META	A	10503S013		METSAHOVI antenna	24 23 04.2	60 14 31.2	62.9
NOUA	A	92701S001		NOUMEA antenna	166 24 37.4	-22 16 10.1	85.3
PURA	A	21604S003		PURPLE MOUNTAIN antenn	118 49 29.3	32 04 01.7	263.5
RIDA	A	40499S016		RICHMOND	279 36 39.7	25 37 25.4	-18.5
ROTA	A	66007S001		ROTHERA antenna	291 52 32.2	-67 34 09.5	26.9
TRIA	A	30604S001		TRISTAN DA CUNHA ant.	347 41 14.9	-37 03 55.0	48.6
WALA	A	92901S001		WALLIS antenna	183 49 13.9	-13 15 56.7	158.9
YELA	A	40127S007		YELLOWKNIFE antenna	245 31 11.6	62 28 51.3	186.4

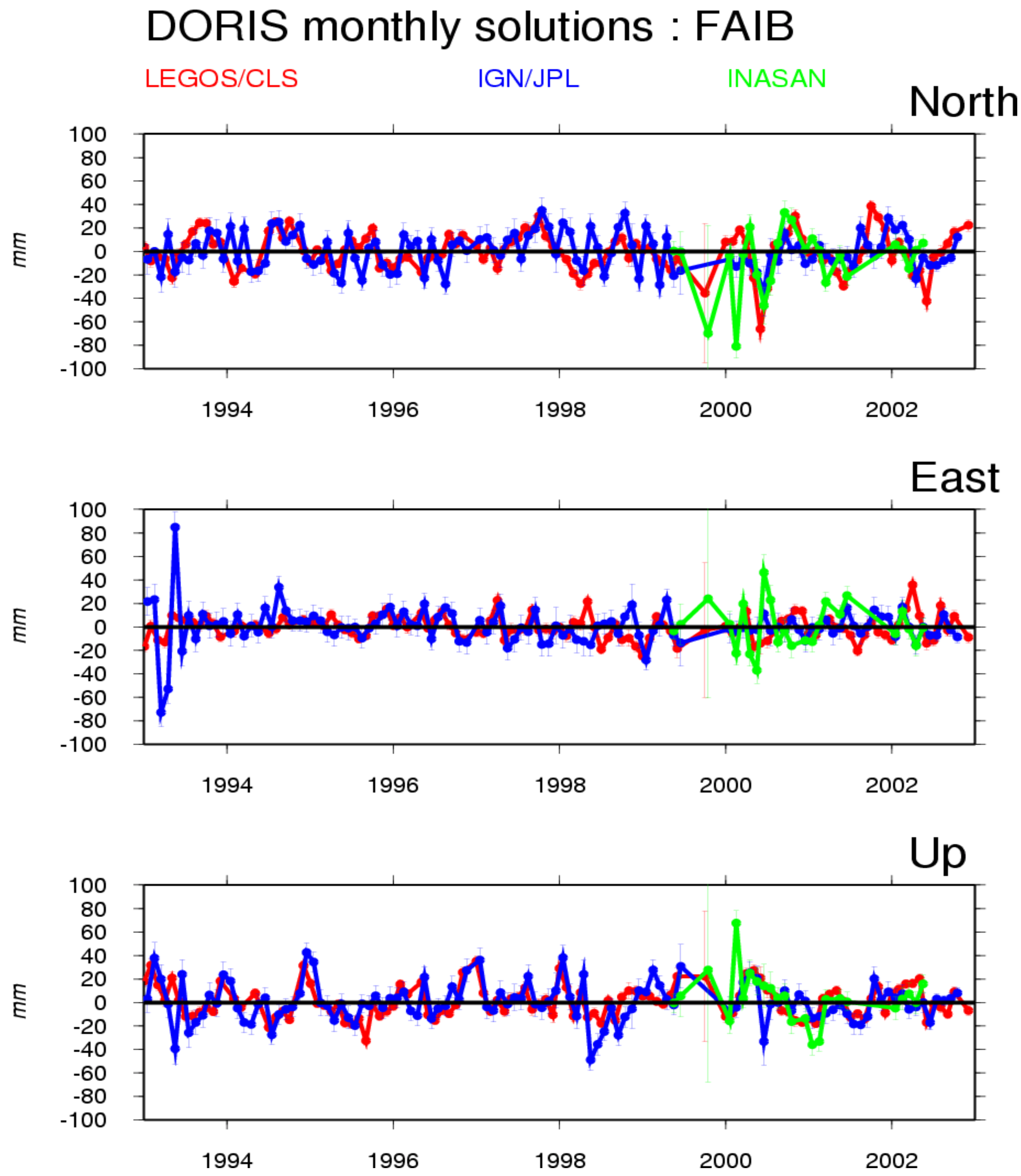
A2 - Ex. of station positions residuals of individual time series combinations

A2.1 Easter Island



ftp://ftp.cls.fr/pub/ids-cls/camp2002/month_analysis/EASB.png

A2.1 Fairbanks



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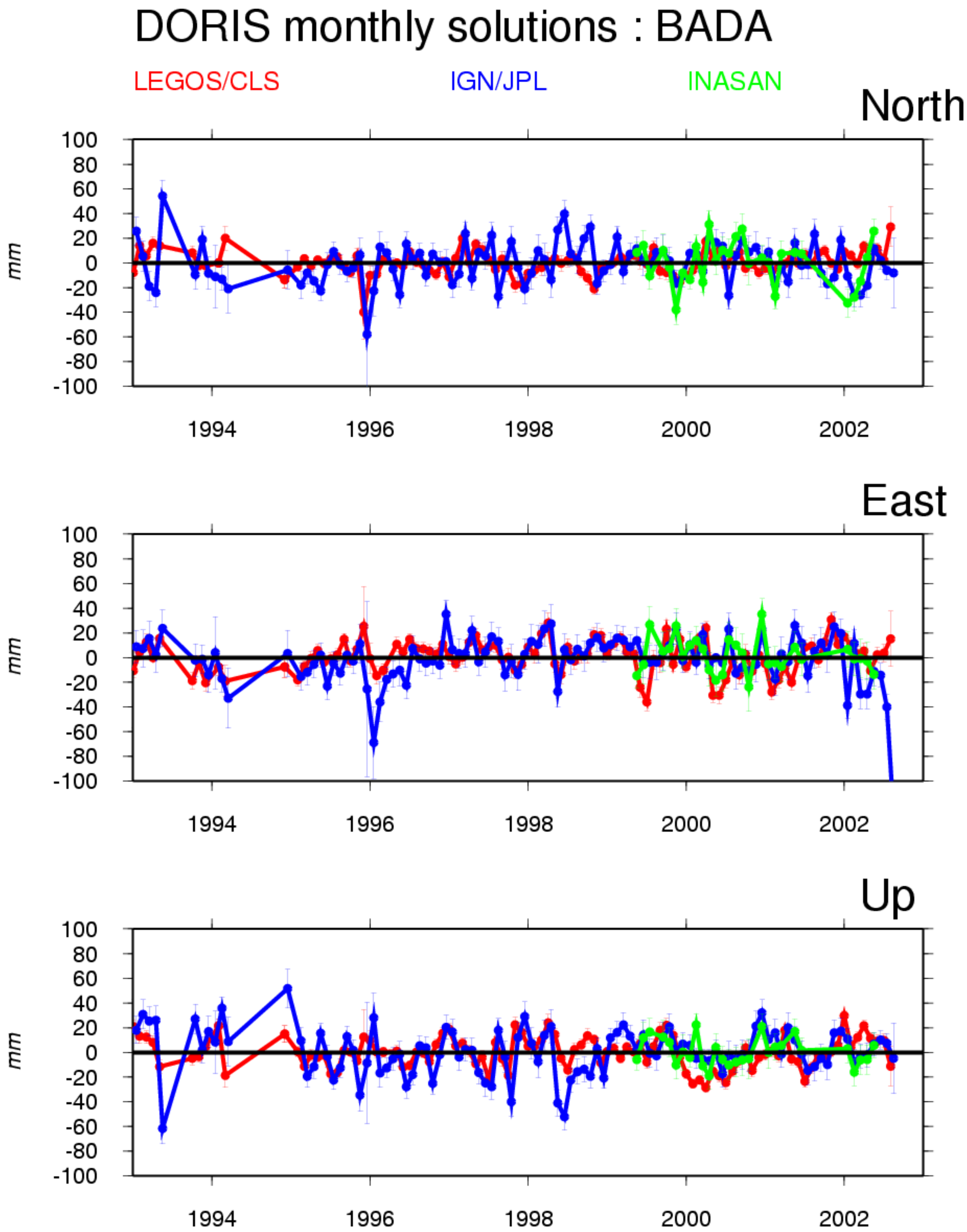
A2.1 Badary



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