Combination at the Observation Level
IERS Working Group

5th COL Working Group Meeting

3 May 2013, DGFI Munich

<u>Agenda</u>

09:00 welcome, *M. Seitz*

09:15 reminder of actions decided at the last meeting, *R. Biancale*

09:30 Status on software and activities in the COL Analysis Centres (15 mn each)

(AIUB/BKG, D. Thaller)
DGFI, M. Blossfeld
ESOC, T. Springer
GFZ, R. Koenig
DIFA/UB, S. Bruni
GRGS, R. Biancale, L. Soudarin
(ASI, C. Sciaretta)
(GSFC, F. Lemoine)
TUW, H. Krasna

11:30 activities in the COL Combination Centres

DGFI, M. Seitz
GRGS, D. Gambis, J.-Y. Richard

12:30 *lunch*

13:30 discussion on activities

14:00 discussion on roadmap (tasks and sequence)

15:00 discussion on combination procedure

16:00 summarizing actions and schedule

16:30 *end of meeting*

COL history

2008 – proposal for creating a WG on Combination at observation level

2009 (21-22 October) – kickoff meeting of the COL-WG / Warsaw

2010 (3 June) – intermediate meeting / Vienna

2010 (9-10 December) – 2nd COL meeting / Munich

2011 (5 April) – intermediate meeting / Vienna

2011 (21-22 November) – 3rd COL meeting / Paris

2012 (29 May) – 4th COL meeting / Munich

2013 (24 January) – GRGS-COL meeting / Toulouse

2013 (5 April) – small intermediate meeting / Vienna

2013 (3 May) – 5th COL meeting / Munich

COL Roadmap (from the charter)

1) **review the approach of the various groups**
   and their capability to process two or more techniques.
2) **elaborating benchmarks**
   to intercompare results between groups from the same data set.
3) **insuring SINEX compatibility**
   between techniques and with the international technique services and IERS.
4) **establishing common processing standards**
   for all techniques in order to guarantee homogeneity and consistency.
5) **optimizing and unifying parameterization**
   for instance for tropospheric parameters in order to minimize globally the degree of freedom of the whole inverse system and to reach consistency.
6) **studying the appropriate weighting between techniques**
   and the use of local ties or identical satellites tracked by several techniques.
7) **studying stabilization methods**
   and looking for high temporal resolution of parameters.
8) **evaluating and comparing results**
   to search for compatibility between groups.
9) **organizing routine operations**
   for a new TRF realization, either in the framework of the next ITRF or as ITRF assessment.

Minutes of the 4th COL Working Group Meeting

29 May 2012 – DGFI/Munich

test period

ACs should process technique data with the defined standards over both test periods CONT08 (10-30 August 2008) and CONT11 (11 September-1 October 2011).

data set

The list of stations used will be reconfirmed, particularly for DORIS (L. Soudarin). Moreover each AC should inform about the number of data used/rejected per technique and per week.

ACs are free to process data from more satellites, for instance Etalon, Starlette, Stella, Jason… This can be particularly of interest for multi-satellite processing as it is done in ESOC.

a priori models

Recommended a priori models are available through the forum. Some ACs have still to implement the NRO formulation. For LEO satellites, the JB2008 drag model is proposed.

parameterization

Pole and UT1 parameters will be provided every 3 hours in (continuous) piece-wise-linear mode (0-3-6-9…-24hr UTC). NRO nutation parameters (in X and Y) will be provided in pwl mode per day (at 0hr UTC).

Wet troposphere parameters should be adjusted every 2 hrs in pwl mode (0-2-4…). A priori values should be the dry tropospheric zenithal delays from GPT/GMF models (TROTOT). Northward/Eastward gradients (TGNDOT/TGEDOT) should be given per day, at least for a few co-located stations.

Parameterization (follow-up)
List of VLBI-GNSS co-locations:
CONT08: Ny Alesund (also DORIS), Onsala, Svetloe Medicina, Wettzell,Tsukuba, Hartebeesthoek (also DORIS), Westford, Kokee Park (also DORIS), Concepcion
CONT11: Ny Alesund (also DORIS), Onsala, Svetloe, Zelenchukskaya, Badary, Yebes, Wettzell,Tsukuba, Hartebeesthoek (also DORIS), Westford, Kokee Park (also DORIS), Concepcion, Hobart
Antenna phase centres for DORIS and GPS should be present.
It is proposed to adjust as well the degree 2 coefficients over each CONT period.

SINEX file compatibility
Most of discrepancies are now solved. However information about models is often missing.
A priori X/Y nutation values should be 0 for all ACs. GRGS has still to provide daily parameters at 0hr UTC (and not every 12hr).
GRGS has still to normalize the ZBIAS parameters (~TROTOT).
Large discrepancies on SLR coordinates of Arequipa, Greenbelt, Fort Davis between GRGS and DGFI/AIUB have to be explained.

weighting
OP will provide variance factors obtained by the Helmert’s variance component estimation method for all normal equations.

comparison strategy
It was agreed last time that ACs will check the SINEX files per technique. According to the minutes of the last meeting Hana Krasna proposed to do it for VLBI, Manuela Seitz for SLR, Frank Lemoine for DORIS, Daniela Thaller for GNSS in order CCs can focus on inter-technique combinations.
Christian Bizouard proposed last time as well to provide Earth’s rotation excitation time series for the time of the CONT08 campaign (1 value/day) for validation purposes. These data should be made available to the COL-WG.
L. Soudarin suggests for the next time that results from ACs should be shown according to a guideline proposed by the coordinators in order to get a better comparative overview.

Parameterizations for the COL campaigns

Parameters	*Parameters to be estimated*	*Initial values*
Pole, UT1-UTC or UT1-TAI	XPO, YPO, UT : PWL @ {00, 03, 06, 09, 12, 15, 18, 21, 24} hr	IERS EOP 08-C04 (tables available on the Forum Multi-technique Combination http://grgs.obspm.fr/forum/)
Pole Rate	XPOR, YPOR 1pt/day @ 12hr	Set to 0
LOD	LOD 1pt/day @ 12hr	Set to 0
Nutation angles	NUT_X, NUT_Y : PWL @ 0hr corrections to the model IAU2000	IERS EOP 08-C04
Station coordinates	SX, SY, SZ at mid epoch	ITRF2008
Radio sources coordinates	RS_RA, RS_DE 1pt/week	ICRF2
Zenithal Tropospheric Delay Wet component & Horizontal gradients	TROWET @ {00, 02, 04, … 24} hr: Adjustment of the wet component to the model TGETOT, TGNTOT daily 00h	GPT/GMF model for radio waves & Mendes/Pavlis for optical waves

Recommended MODELS for the COL campaign
Available on the Forum Multi-Technique Combination http://grgs.obspm.fr/forum/

Gravity Field	EIGEN model computed from GRACE-GOCE completed by the mean gravity variations of the atmosphere and the non-IB oceanic response
Ocean Tides Loading	FES2004 check at the triple co-location sites
Troposphere Delay	GPT+GMF for radio-electrical waves, Mendes-Pavlis for optical waves
Atmospheric Tide Model	Modified Ray-Ponte (2003)
Atmospheric Loading	Not applied

28 SLR stations

Code	Domes	
7845	10002S002	GRASSE
7839	11001S002	GRAZ
7811	12205S001	BOROWIEC
1884	12302S002	RIGA
1873	12337S003	SIMEIZ
7941	12734S008	MATERA (MLRO)
7840	13212S001	HERSTMONCEUX
7824	13402S007	SAN FERNANDO
7810	14001S007	ZIMMERWALD
7841	14106S011	POTSDAM2
8834	14201S018	WETTZELL
7832	20101S001	RIYADH
7249	21601S004	BEIJING
7821	21605S010	SHANGHAI
7237	21611S001	CHANGCHUN
7308	21704S002	KOGANEI
7838	21726S001	SIMOSATO
7501	30302M003	HARTEBEESTHOEK
7080	40442M006	MCDONALD
7119	40445M004	HALEAKALA
7105	40451M105	GREENBELT
7110	40497M001	MONUMENT PEAK
7406	41508S003	SAN JAN
7405	41719M001	CONCEPCION
7403	42202M003	AREQUIPA
7090	50107M001	YARRAGADEE
7825	50119S003	MOUNT STROMLO
7124	92201M007	TAHITI

45 DORIS stations

Code	Domes	
TLSB	10003S005	Toulouse
REZB	10202S003	Reykjavik
SPJB	10317S005	Ny-Alesund
METB	10503S015	Metsahovi
KIUB	12334S006	Kitab
BADB	12338S002	Badary
DIOB	12602S012	Dionysos
JIUB	21602S005	Jiufeng
MANB	22006S002	Manille
CICB	23101S002	Cibinong
HBMB	30302S008	Hartebeesthoek
MATB	30313S003	Marion-Island
ASDB	30602S004	Ascension
HEMB	30606S004	St-Helena
PDMB	31906S002	Ponta-Delgada
LICB	32809S004	Libreville
SALB	39601S002	Sal
MAHB	39801S005	Mahe
DJIB	39901S003	Djibouti
STJB	40101S002	St-Johns
YEMB	40127S009	Yellowknife
KOLB	40424S009	Kauai
GREB	40451S176	Greenbelt
RIQB	41507S006	Rio-Grande
CADB	41609S002	Cachoeira
EASB	41703S009	Easter-Island
SANB	41705S009	Santiago
ARFB	42202S007	Arequipa
THUB	43001S005	Thule
MIAB	49914S003	Miami
YASB	50107S011	Yarragadee
MSPB	50119S004	Mount-Stromlo
CHAB	50207S001	Chatam
SYPB	66006S003	Syowa
ROUB	66007S003	Rothera
BEMB	66018S002	Belgrano
KETB	91201S005	Kerguelen
CRPB	91301S002	Crozet

Code	Domes	
AMUB	91401S004	Amsterdam-Island
ADFB	91501S003	Terre-Adelie
PATB	92201S010	Papeete
NOWB	92701S003	Noumea
FUTB	92902S001	Futuna
KRVB	97301S004	Kourou
REUB	97401S002	La-Reunion

12 VLBI stations

Code	Domes	
7331	10317S003	NYALES20
7213	10402S002	ONSALA60
7380	12350S001	SVETLOE
7381	12351S001	ZELENCHK
7230	12711S001	MEDICINA
7224	14201S004	WETTZELL
7345	21730S007	TSUKUB32
7232	30302S001	HARTRAO
7209	40440S003	WESTFORD
7298	40424S007	KOKEE
7297	41602S001	FORTALEZA
7640	41719S001	TIGOCONC

144 GPS stations

Code	Domes	Code	Domes	Code	Domes	Code	Domes
gras	10002M006	zimj	14001M006	drao	40105M002	bogt	41901M001
tlse	10003M009	pots	14106M003	nrc1	40114M001	areq	42202M005
reyk	10202M001	wtzr	14201M010	yell	40127M003	thu3	43001M002
hofn	10204M002	wtza	14201M013	albh	40129M003	kely	43005M002
tro1	10302M006	wtzz	14201M014	flin	40135M001	qaq1	43007M001
nyal	10317M001	nico	14302M001	whit	40136M001	cro1	43201M001
Nya1	10317M003	ramo	20703S001	dubo	40137M001	tidb	50103M108
onsa	10402M004	ankr	20805M002	wslr	40141M001	yarr	50107M006
kiru	10403M002	wuhn	21602M001	holm	40148M001	park	50108M001
mar6	10405M002	shao	21605M002	reso	40149M001	hob2	50116M004
metz	10503M005	kunm	21609M001	invk	40150M001	str1	50119M002
mets	10503S011	usud	21729S007	alrt	40162M001	coco	50127M001
graz	11001M002	tskb	21730S005	jplm	40400M007	pert	50133M001
bor1	12205M002	mtka	21741S002	gold	40405S031	darw	50134M001
riga	12302M002	pimo	22003M001	fair	40408M001	mac1	50135M001
irkj	12313M002	iisc	22306M002	kokb	40424M004	jab1	50136M001
yssk	12329M003	hyde	22307M001	wes2	40440S020	alic	50137M001
kit3	12334M001	ntus	22601M001	mdo1	40442M012	cedu	50138M001
pol2	12348M001	bako	23101M002	maui	40445S008	chat	50207M001
svtl	12350M001	twtf	23603S002	gode	40451M123	auck	50209M001
zeck	12351M001	ulab	24201M001	usno	40451S003	ous2	50212M002
yakt	12353M002	yibl	25001M001	wdc3	40451S008	kiri	50305M001
petp	12355M002	hrao	30302M004	pie1	40456M001	guam	50501M002
tixi	12360M001	harb	30302M009	nlib	40465M001	cnmr	50512M001
artu	12362M001	suth	30314M002	amc2	40472S004	mcm4	66001M003
nril	12364M001	rbay	30315M001	mkea	40477M001	maw1	66004M001
medi	12711M003	dgar	30802M001	monp	40497M004	syog	66006S002
mate	12734M008	mas1	31303M002	scub	40701M001	ohi3	66008M006
mat1	12734M009	pdel	31906M004	cic1	40508M002	dav1	66010M001
hers	13212M007	nklg	32809M002	lpgs	41510M001	cas1	66011M001
hert	13212M010	mali	33201M001	brft	41602M002	guug	82301M001
sfer	13402M004	mbar	33901M001	braz	41606M001	kerg	91201M002
vill	13406M001	rabt	35001M002	chpi	41609M003	thti	92201M009
madr	13407S012	sey1	39801M001	ispa	41703M007	nrmd	92701M005
yebe	13420M001	stjo	40101M001	sant	41705M003	kour	97301M210
zimm	14001M004	algo	40104M002	conz	41719M002	reun	97401M003

IERS COL-WG project
GRGS Analysis Centers

R Biancale, F Perosanz, J-M Lemoine / CNES

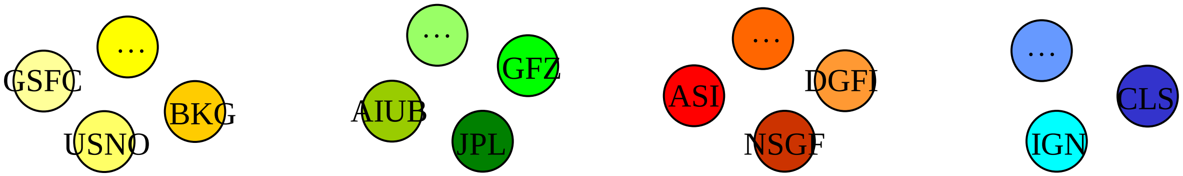
F Deleflie / Observatoire de Paris-IMCCE

S Loyer, L Soudarin / CLS

G Bourda / Observatoire de Bordeaux

Current approach

VLBI	GPS	SLR	DORIS



Weekly EOP and TRF SINEX

Combination Center

Example: ITRF2005

Alternative approach

VLBI GPS SLR DORIS

Ex.: **GINS software**

Same modeling

Same standards

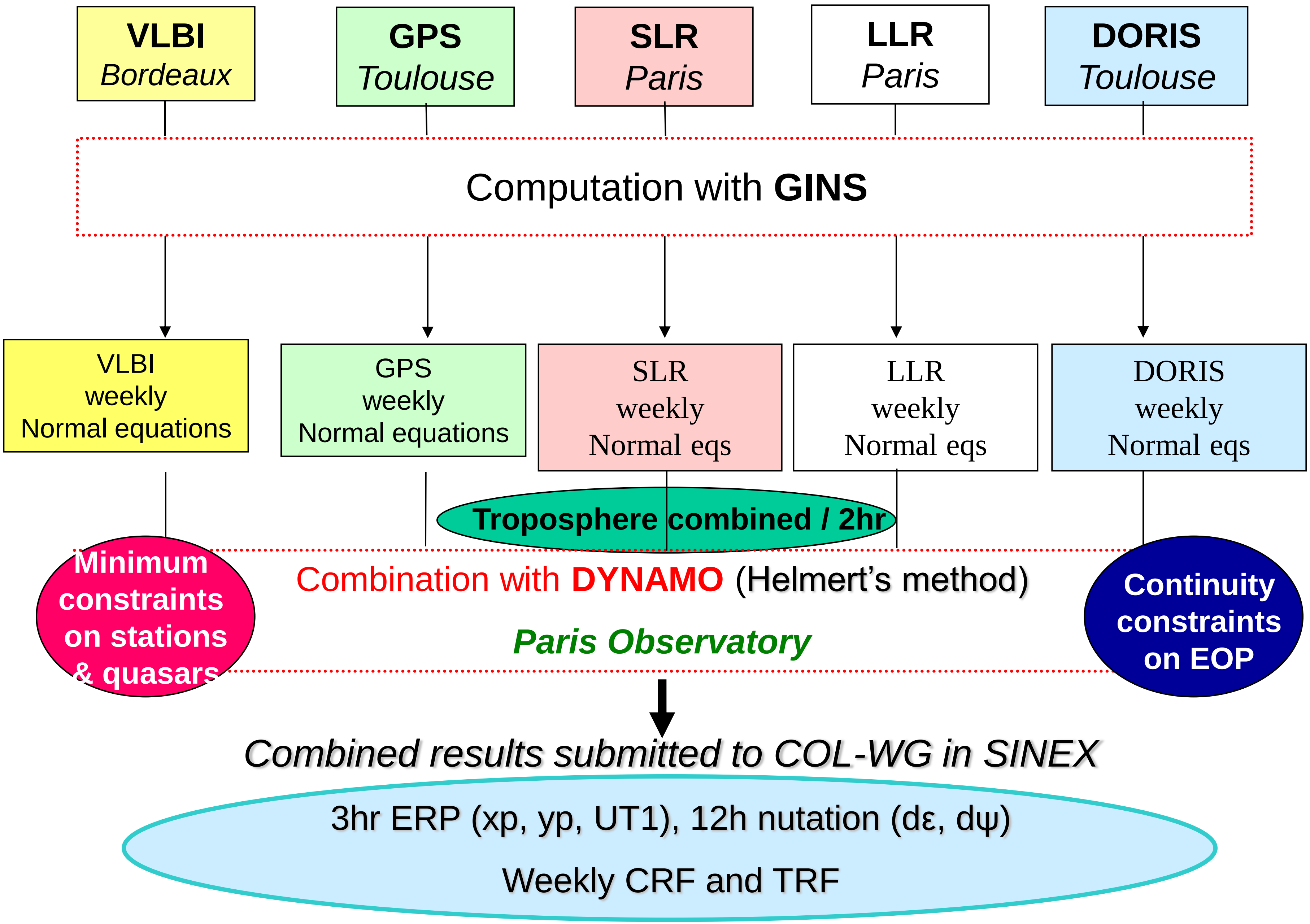
NEQs stacking

Ex.: **DYNAMO software**

Weekly Combination EOP+TRF+..

D Gambis, GGOS-IERS Unified Analysis Workshop 2007 Monterey

Combination at the observation level

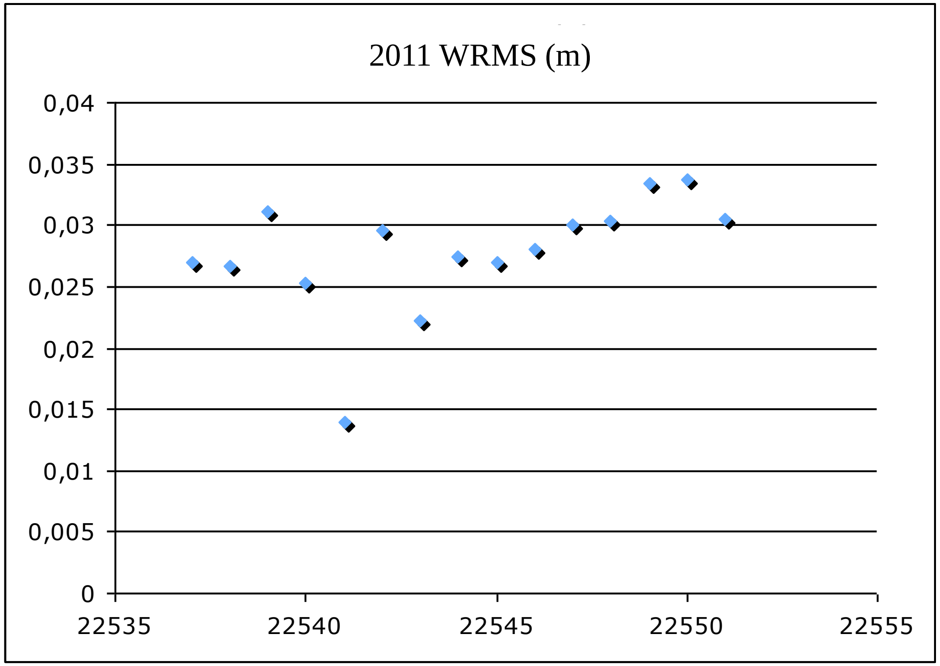


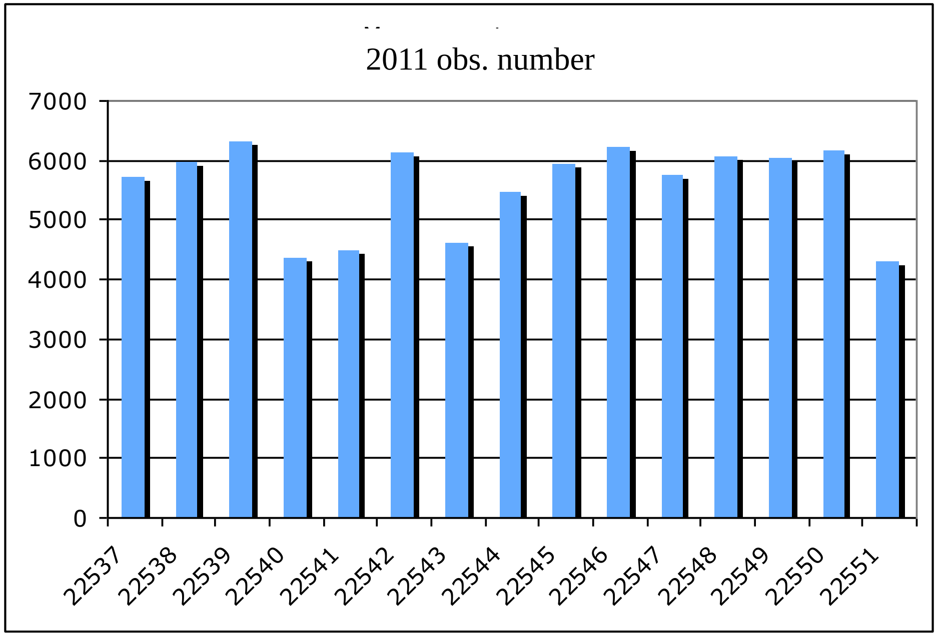
VLBI-AC / OB

(G. Bourda)

Session	**CONT08**	**CONT11**
from	12 August 08	15 Sept. 11
To	26 August 08	29 Sept. 11
processed	per week	per day
Models		
A priori Pole	NRO	NRO
Pole & UT1	each 3hr	each 3hr
Wet Tropo	each 2hr	each 2hr
Dry Tropo	GPT/GMF	GPT/GMF
Ocean Loading	Scherneck	Scherneck

2008 weeks	**RMS (m)**	**Obs. number**
33	0.013733	37699
34	0.010922	51500
35	0.012782	26726





SLR-AC / OP *(F. Deleflie)*

LAGEOS (3/9/2011 -

22530.00000	LASER:CC|	0.018559	0.016444	2455 mesures (	39 eliminees)	metre
22537.00000	**?**					
22544.00000	**LASER:CC|**	**0.015284**	**0.012763**	**2419 mesures (**	**63 eliminees)**	**metre**
22551.00000	**LASER:CC|**	**0.010789**	**0.009379**	**?058 mesures (**	**164 eliminees)**	**metre**
22558.00000	LASER:CC|	0.011781	0.010212	2269 mesures (	70 eliminees)	metre

LAGEOS-2

22530.00000	LASER:CC|	0.018268	0.016578	2445 mesures (	44 eliminees)	metre
22537.00000	**LASER:CC|**	**0.019907**	**0.018097**	**2170 mesures (**	**16 eliminees)**	**metre**
22544.00000	**LASER:CC|**	**0.018207**	**0.016781**	**1869 mesures (**	**3 eliminees)**	**metre**
22551.00000	**LASER:CC|**	**0.017005**	**0.014997**	**2390 mesures (**	**103 eliminees)**	**metre**
22558.00000	LASER:CC|	0.013807	0.012054	1844 mesures (	21 eliminees)	metre

IDS, IGS, ILRS, IVS & COL standards to get ready for the GRGS contribution to ITRF2013

Gravitational Dynamic	DORIS	GNSS	SLR	LLR	VLBI	COL
Geopotential	EIGEN-6S2 up to degree 95 including time variable terms up to degree 50 (bias & drift per yr from 2002 to 2012, periodic 18.6, 1, 0.5 yrs)	EIGEN-6S2 up to degree 12	EIGEN-6S2 up to degree 30 (for LAGEOS)			Static gravity field model is based on EIGEN-GRGS.RL02, tide-free, complete to degree and order 2 up to 160 ftp://hpiers.obspm.fr/iers/eop/grgs/Models/Gravity_Field/
Third-body	JPL DE421	JPL DE421	JPL DE421		JPL DE421	JPL DE405
Solid Earth Tides	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards			IERS 2010 standards
Ocean Tides	FES 2012 (32 principal waves, + 60 admittance waves) up to degree 50	FES 2012 (32 principal waves, + 60 admittance waves) up to degree 12	FES 2012 (32 principal waves, + 60 admittance waves) up to degree 20			FES 2004 ftp://hpiers.obspm.fr/iers/eop/grgs/Models/Ocean_Tide_Loading/
Atmospheric gravity	3hr ERA-interim / ECMWF up to degree 50	3hr ERA-interim / ECMWF up to degree 12	3hr ERA-interim / ECMWF up to degree 20			none (integrated into the geopotential)
Non tidal oceanic gravity	TUGO R12 up to degree 50	TUGO R12 up to degree 12	TUGO R12 up to degree 20			none (integrated into the geopotential)
Atmospheric tides	none (considered through the ECMWF atmospheric data)	none	none			Ray & Ponte 2003 ftp://hpiers.obspm.fr/iers/eop/grgs/Models/Atmospheric_Tide/
Earth pole tide	IERS2010 standards	IERS2010 standards	IERS2010 standards			IERS2010 standards
Ocean Pole Tide	Desai 2002 up to degree 12	Desai 2002 up to degree 12	Desai 2002 up to degree 12			Desai 2002 up to degree 12

Non Gravitational Dynamic	DORIS	GNSS	SLR	LLR	VLBI	COL
Atmospheric drag	DTM2012 (with Am indices) Spots, Envisat, Cryosat2, HY-2A: one coef/4 hrs (one/1hr in high solar activity periods) ; Topex, Jasons: one coef/half day		DTM2012 None for Lageos			JB2008
Solar radiation pressure	one coef/day strongly constrained (1.e-4) to: 0.98 for Topex; 1.15 for Spot-2; 1.16 for Spot-3/-4; 1.17 for Spot-5; 1.29 for Envisat; 0.97 for Jason-2; 0.85 for Cryosat-2; 1.13? for HY-2A	one coefficient adjusted per day?	one scale coefficient adjusted per arc			applied
Albedo + infra-red	interpolated from grids issued from ECMWF 6hr 4.5° grids	interpolated from grids issued from ECMWF 6hr 9° grids	interpolated from grids issued from ECMWF 6hr 9° grids			applied
Satellite emissivity	none	none	none			none
Relativity	Schwarzschild model + Lense-Thirring + geodetic precession	Schwarzschild model + Lense-Thirring + geodetic precession	Schwarzschild model + Lense-Thirring + geodetic precession		IERS 2010 standards	Schwarzschild model + Lense-Thirring + geodetic precession
Hill/empirical	once/rev along-& cross-track per x day		once/rev along-& cross-track per x day			

Geometry	DORIS	GNSS	SLR	LLR	VLBI	COL
Earth reference system	DPOD2008	Set of 50-60 station coordinates & velocities from ITRF2008 & IGb08	ITRF2008 (SLRF2008)		VTRF2008	ITRF 2008
Celestial reference system	inertial J2000	inertial J2000	inertial J2000		J2000, ICRF2	J2000, ICRF2
Pole & UT1	daily EOPC04_i08	daily EOPC04_i08	daily EOPC04_i08		daily EOPC04_i08	EOPC04 initial values interpolated (Lagrange polynomial method) with 3hr time intervals generated by EOP Center
Precession / Nutation	IERS 2010 using NRO origin	IERS 2010 using NRO origin	IERS 2010 using NRO origin		IERS 2010 using NRO origin	IAU2000A - IAU2006 a-priori set to zero
Solid Earth tidal displacement	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards		IERS 2010 standards	IERS 2010 standards
Ocean loading	FES2012	FES2012	FES2012		FES2012	Ocean tide loading models per stations are obtained from Scherneck's ocean loading site and provided in the BLQ format according to the IERS Standards 2010
Tidal atmospheric loading	S1/S2 Ray & Ponte (2003)	S1/S2 Ray & Ponte (2003)	S1/S2 Ray & Ponte (2003)		S1/S2 Ray & Ponte (2003)	none
Non tidal atmospheric loading	none	none	none		none	none
Solid pole tide displacement	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards		IERS 2010 standards	IERS 2010 standards
Ocean pole tide displacement	none	none	none		none	none

Propagation & Systems	DORIS	GNSS	SLR	LLR	VLBI	COL
Troposphere	GPT/GMF modelling from Boehm et al. (2006). One zenith delay/pass + one daily tropospheric gradient per station in North & East directions	GPT/GMF modelling from Boehm et al. (2006). One zenith delay/2hr using PWL, continuous model + one daily tropospheric gradient per station in North & East directions	Mendes-Pavlis: (zenith delay & mapping Function)		GPT/GMF modelling from Boehm et al. (2006). One zenith delay/2hr + one daily tropospheric gradient per station in North & East directions	GPT/GMF for radio-electrical waves and Mendes-Pavlis for SLR. One zenith delay/2hr or pass + one daily tropospheric gradient per station in North & East directions
Ionosphere	2nd order corrections using IGS TEC values and igrf2011 magnetic field model	2nd order corrections using IGS TEC values and igrf2011 magnetic field model				none
Satellite system	Centre of mass / Phase centre vector from macro model + attitude law No phase law applied	Centre of mass offsets / Phase centre corrections from file: igs08_wwww.atx	Centre of mass corrections from G. Appleby			
Ground system	Phase centre / reference point vector from manufacturer values Phase law applied	Absolute elevation/azimuth dependent phase centre corrections are applied according to igs08_wwww.atx			Antenna thermal expansion: Nothnagel (2008) Antenna axes offset: IVS files	
Elevation cut-off	12 degrees Down weighting law for elevation <= 20 deg; Weight of the observation is multiplied by the factor elevation**2/400 with elevation in degrees)	10 degrees	10 degrees		12 degrees	

Determination of terrestrial frames by optimal combination of GNSS, DORIS and SLR measurements

M. Zoulida[1], A. Pollet[1], D. Coulot[1], R. Biancale[2] email : myriam.zoulida@ign.fr

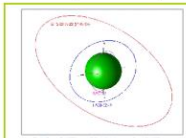
[1]Institut National de l'Information Géographique et Forestière– LAREG, Université Paris Diderot, GRGS, Paris, France [2] Observatoire Midi-Pyrénées, GET, Toulouse, France

Abstract

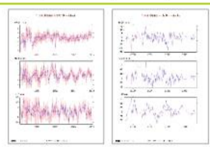
Les combinaisons directes de mesures géodésiques revêtent une importance particulière dans le cadre de GGOS (Global geodetic observing system - www.ggos.org) et ont de nombreux objectifs : réalisation de repères de référence très exacts, calcul de séries temporelles de paramètres géodésiques/géophysiques de grande qualité, inter-comparaison des techniques géodésiques, etc. Chaque technique de géodésie spatiale a ses avantages et ses inconvénients, et leur combinaison permet d'exploiter simultanément et au mieux les premiers, et d' atténuer les effets des seconds. Il a été montré qu'il était possible et avantageux (en particulier pour la rotation de la Terre) de combiner les mesures directement (Combination at Observation Level – COL) mais que, même dans ce cadre, il était toujours nécessaire de rattacher les repères terrestres des techniques entre eux, afin d'obtenir un repère combiné homogène. Jusqu'ici, ceci a été réalisé en utilisant des rattachements locaux au sol, pour des sites où sont disponibles plusieurs techniques. Cependant l'utilisation de rattachements locaux dans des calculs hebdomadaires reste encore problématique. Afin de diminuer l'impact des rattachements dans la combinaison, une approche différente consiste à rajouter des "rattachements spatiaux", tels que ceux fournis par les satellites dits multi-techniques. Sur ce sujet, des résultats prometteurs ont été obtenus récemment mais toujours pour des combinaisons de sous-jeux de toutes les données disponibles. Les buts de ces travaux de thèse sont multiples : définir la stratégie d'estimation des paramètres caractérisant les rattachements spatiaux dans un calcul commun pour les orbites des satellites et les repères terrestres, réaliser des calculs d'orbites intégrés (un seul traitement pour toutes les techniques) et étudier la possibilité d'utilisation des seuls rattachements spatiaux pour le calcul de repères terrestres.

Combination of geodetic techniques' measurements : Why ?

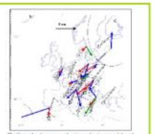
•Each technique has a different sensitivity, regarding various phenomena which affect it (gravity field, friction forces ...).
•Each technique has different precision and senses the same phenomena in different ways
•Each technique has advantages and defects (VLBI, the unique technique which is sensitive to UT ...).



Orbits of different techniques' satellites
GPS BIIA-23 : GNSS
LAGEOS 2: SLR
SPOT 5: DORIS



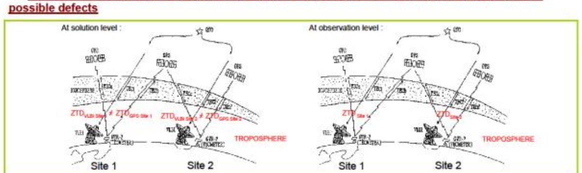
GPS DORIS
Residual time series retrieved from ITRF web site (http://itrf.ign.fr/)



Estimated annual signals in residual series of height : GPS (red), VLBI (green), and SLR (blue). Vector norm represents the signal's amplitude and the phase orientation [4].

Using same models and software for all techniques ⇒ Coherent process
Using more information during the combination :
New common parameters as Zenithal Tropospheric Delays (ZTD), spatial link with multi-technique satellites ...

⇒ **Combining techniques in order to make the best use of each technique and reduce the effect of possible defects**



⇒**Combining at observation level in order to better use all the information provided by techniques**

Combination products

Actual products of space geodetic combination : Terrestrial reference frame (as ITRF), EOP time series, gravity field models, etc.

Possible products in the future : Reference frames (terrestrial and celestial), EOP time series, gravity field, orbits, tropospheric maps... in same process

Measurements to combine – Local ties

Currently, for terrestrial reference frame and EOP time series

DORIS Orbitographic system, best station network regarding the geographical distribution

GPS Most precise positioning technique, the largest number of stations and observations

SLR Most precise regarding the gravity field and,thus, geocenter. Insensitive to water vapour

VLBI Sole technique providing Universal Time and ICRF

Local Ties (LT): Terrestrial links between all techniques on co-location sites, provided by topometric measurements
They are necessary in order to accomplish homogeneous combinations since the terrestrial frames yielded by each technique's observations have to be tied with each other [12].
GPS is the main link between techniques, since many other techniques instruments are co-located with a GPS antenna. Estimating by space geodesy the vector between GPS and every other technique on co-location sites, and comparing this vector with the available local ties allows the assessment of local ties.

Downsides of LT:
• The LT and the coordinate differences from space-geodetic observations often mismatch.
In [1], are summarized discrepancy percentages, in the case of ITRF2008, regarding residuals of GPS-to-other-techniques vectors between space geodesy estimations and available local ties. Less than half of these are below 6mm, but it is not possible to reduce the network down to these, for the uncertainties of estimated parameters will increase greatly.

• Geographical distribution of these ties is often problematic for weekly calculations.
Indeed, if local ties give us link between technique networks, we need only 7 constraints to define the combined frame. But local ties between each technique networks are not necessarily well distributed and have different quality. This introduces deformations for each technique's network in the combination [11].

Discrepancy (mm)	GPS - VLBI	GPS - SLR	GPS - DORIS
<6	47	43	34
6-10	24	29	12
>10	29	28	54

Table 1 :Tie discrepancy percentage

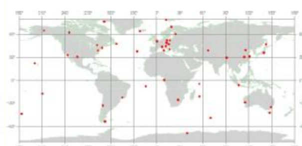


Figure 1 : Weekly local ties distribution [11]

Space ties – Multi-technique satellites

Space ties: multi-technique satellites can be considered as co-location sites in space.

Figure 2 : Multi-technique satellites [9]

Space ties yield the following benefits:
• Densification of co-locations: two non-co-located stations using different techniques, can be considered co-located on the satellite, given that they both observe it at the same period of time [14].
• Inter-calibration of techniques as the satellites' orbits can be calculated as common parameters between techniques [15].
• Independent control of geodetic LT, as long as they are estimated in the same RF, since they are not used in the combination, but the station coordinates are estimated with the other parameters [15].

Space ties – Multi-technique satellites

Main downside of space ties: ambiguities in the precise location of the instruments' reference points on the satellites with respect to the satellite's center of mass.

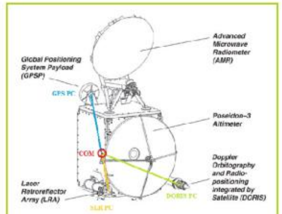


Figure 3 : http://www.nasa.gov/ - Jason-2 mission

1. The GPS antenna phase center varies depending on the signal's propagation azimuth angle [13].
2. The DORIS antenna phase center varies depending on the signal's reception azimuth angle and elevation angle [16].
3. The SLR array estimated position is affected by the photon return satellite signature [8],[10].
4. For satellites as Jason-2, the center of mass (COM) position is not constant through time, because of the fuel consumption of the satellite [10].

One of this study's goals is to define a method of estimation and quality assessment for the vectors between these points and the satellite's center of mass.

Some recent studies:

1. **GNSS and SLR on GNSS satellites:** GNSS orbits determined from GNSS and SLR with satellite antenna offset (SAO) and Laser Retro-reflector Array offset (LRA) estimated w.r.t. COM as space ties [15]. Validation of space ties: comparing estimated SAO and LRA with the ones provided by IGS (igs08.atx) and ILRS respectively shows some inconsistencies (-1.4mm GPS/-16.1mm GLONASS for LRA and -86.1mm GPS/-110.4mm GLONASS for SAO). LT validation: comparing estimated coordinates with known LTs shows that most horizontal components agree at better than 1 cm. Station height component discrepancies are larger: 27/55 co-locations agree better than 1 cm but improve when SAO and LRA offsets were estimated as shown in figure 4.

Figure 4 : Impact of space ties on height differences in LTs [15].

2. **Multi-technique combinations on Jason-2 satellite:** recent tests [14] have shown that adding multi-technique observations for Jason-2 orbit estimation, improved the GPS satellites orbits estimation residuals w.r.t. GRGS nominal orbits (better RMS_{3D}). Also, GPS ground station position estimation adding Jason-2 observations has shown improvement w.r.t. ITRF2008, namely on the Z component, where large offsets are observed in GRGS solutions.
3. **LEO-Based Calibrations of GPS Transmit Antennas:** the use of Low Earth Orbiters (LEO) diminishes the effects of troposphere and multipath and also allows the use of Precise Orbit Determination (POD) to provide constraints on the scale and the TRF [7]. Origin and scale components obtained with the use of the estimated Phase Center Variation (PCV) show good agreement with the IGS08 reference frame.

Conclusion – Perspectives

As shown, results on the use of space ties are promising, but still not available on an integral use of all available data. In this study, we aim to use more multi-technique satellites, such as GRACE twin satellites (*GNSS – SLR*), Cryosat-2 (*SLR – DORIS*), HY2A (*GNSS – DORIS – SLR*), Saral-Altika (*GNSS – DORIS – SLR*), Sentinel – 3A (*GNSS – DORIS – SLR*), Jason – 3 (*GNSS – DORIS – SLR*), which, all combined, can create a dense network around the globe, with multiple co-location spots. Other satellites will be used as well, such as the SLR-only ones LAGEOS 1/2 and Etalon 1/2, the DORIS-only SPOT 2/4/5 and the GNSS ones (GPS, GLONASS and GALILEO).
Moreover, it will be necessary to establish a calculation strategy in order to estimate the parameters that characterize the space ties, which, as shown above, play a major role in the improvement of estimated LT coordinates and their coherence with the available ones.
Finally the GRASP (Geodetic Reference Antenna in Space) mission [3], that came second in NASA mission selection on 2012, would have combined all four techniques on a single satellite, to enhance the accuracy of precision GNSS applications and POD and to improve gravity and altimetry records. This proposal shows the growing interest in space techniques combination and, if accepted in the near future, would become a valuable asset to space ties combinations.

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