A NEW VELOCITY FIELD FOR AFRICA FROM COMBINED GPS AND DORIS SOLUTIONS: CONTRIBUTION TO AFREF

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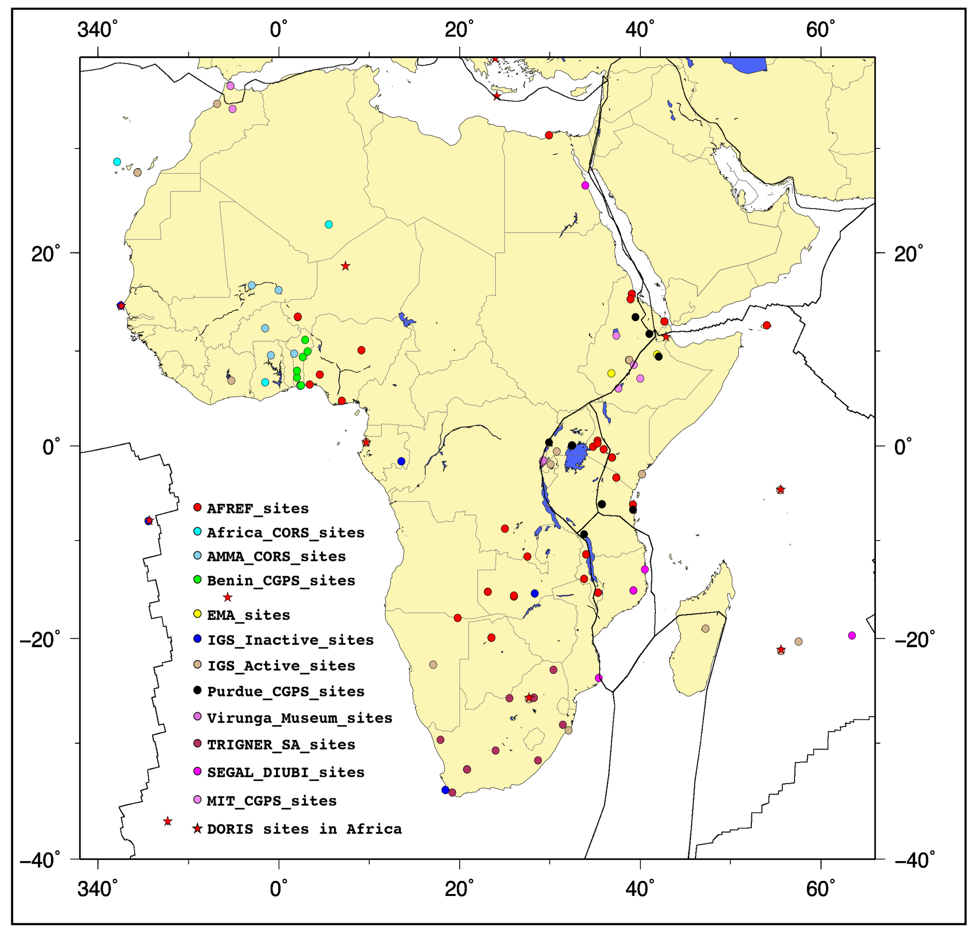
1. INTRODUCTION

Starting in early 2003, scientists and survey division from African countries identified the need to establish a unified geodetic reference frame for Africa (African Reference Frame - AFREF). Such a frame would serve for inter-country engineering, mapping, resolve national boundary problems and importantly facilitate geophyiscal interpretation, in particular motion across the East African Rift system (EARS).

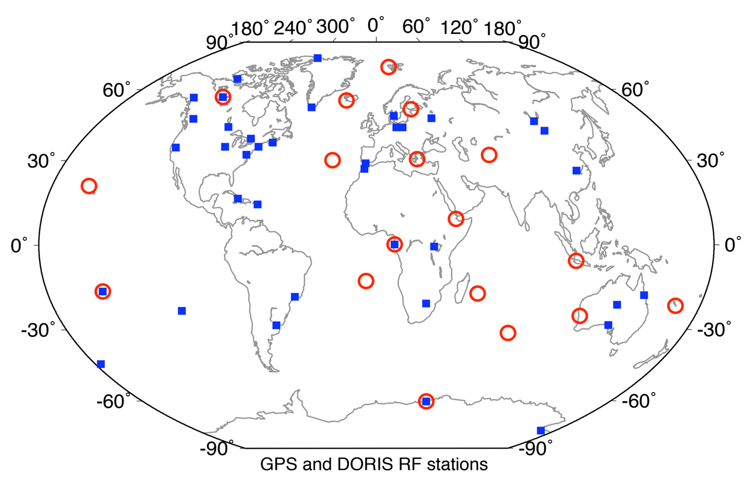
This work is a contribution to AFREF by providing a first position/velocity solution for about 100 continuous GPS stations and 9 DORIS station operating in Africa, in a well-established global reference frame (International Terrestrial Reference Frame, ITRF2008) based on 15 and 18 years of data for GPS and DORIS respectively. The resulting velocity field describes horizontal plate motion at all aforementioned sites operating in Africa. We use the resulting velocities to estimate the rotation vector describing the motion of the stable Nubian plate with respect to ITRF2008, since the reference frame for Africa is likely to be fixed to the Nubian plate in order to minimize coordinate time dependencies, as the primary purpose of AFREF is geo-referencing for practical surveying applications. We also investigate the kinematics in East Africa to quantify the rate of internal deformation of such a static frame.

Example of AFREF installed continuous GPS station in Tanzania (TANZ), with the support of the U.S.A. National Science Foundation, in collaboration with Ardhi University-Tanzania, In the west northern part of Dar es Salaam

2. GPS AND DORIS SITES IN AFRICA

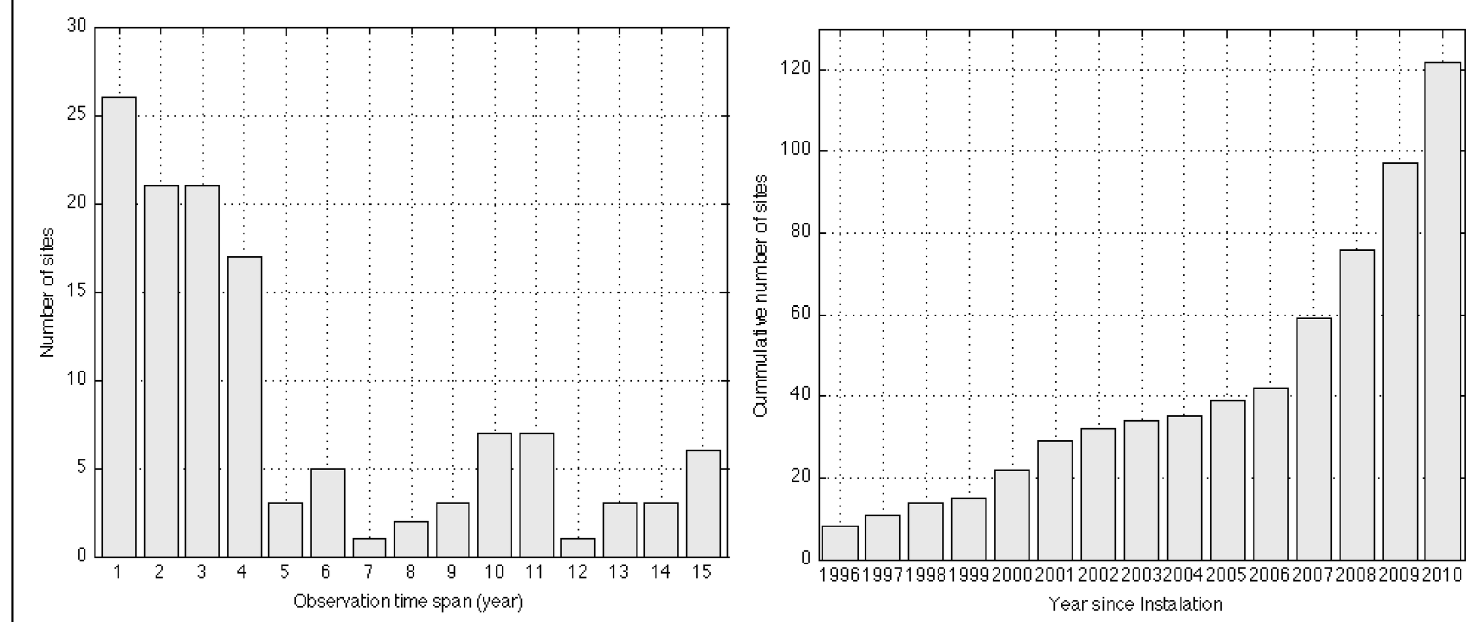


The figure to the right shows the GPS and DORIS global core sites used in the minimal constraints approach with respect to ITRF2008 in their individual staking using CATREF software. GPS sites are shown in blue and Doris sites in red. We used the same Local tie vector used in ITRF2008 realization. The collocated sites were constrained to have the same velocity averaged (in least squares sense) according to the common observation intervals 1996 – 2011.

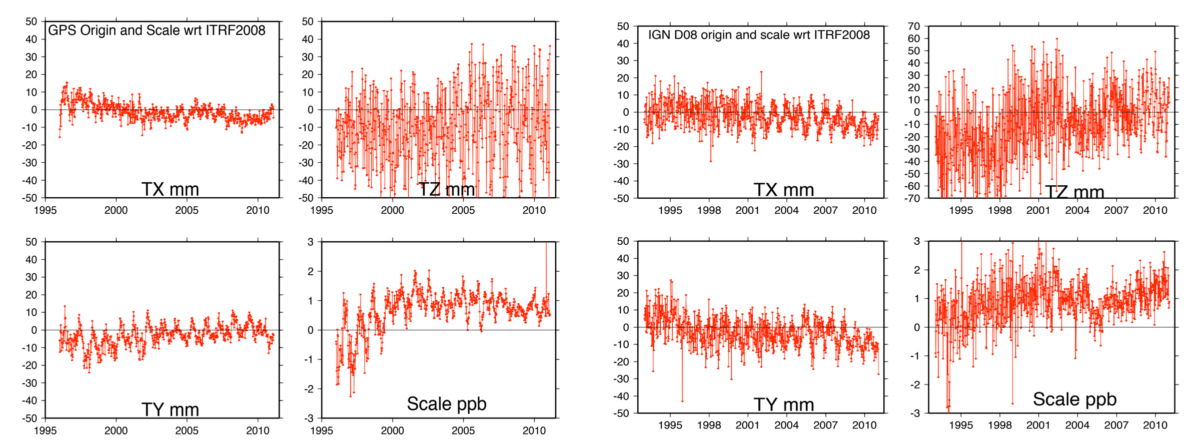


3. STATISTICS OF AVAILLABLE GPS SITES IN AFRICA

Figures below illustrate the publicly available GPS sites in Africa. A number of continuous GPS stations still remain private. Most of the publicly available sites have been operating for less than 4 years, with a sharp increase in the number of sites in the year 2009. This also means that in less than 2 years the number of CGPS sites usable for reference frame and tectonic studies will have increased by a factor of three.

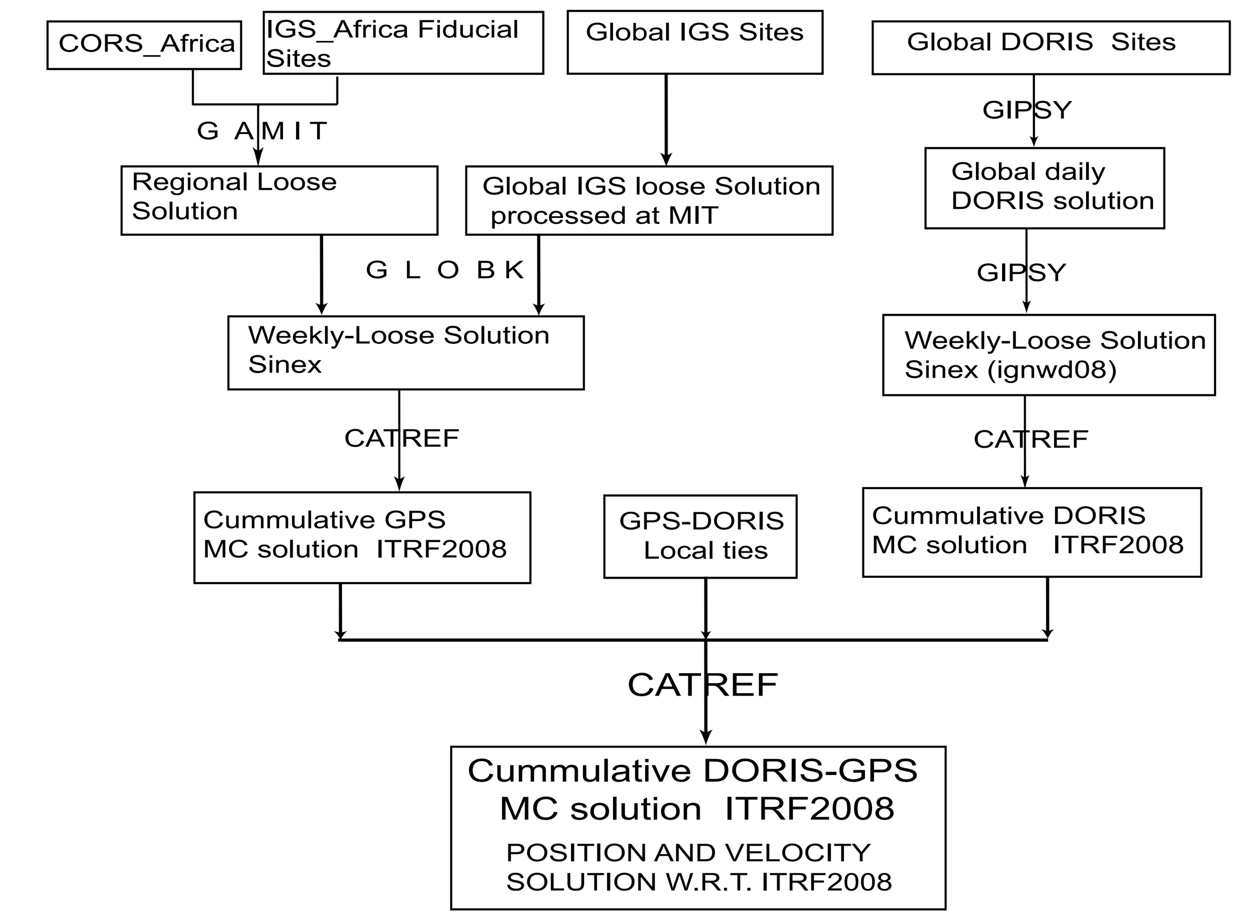


Figures to the right shows the variation of the translation components and scale for GPS and DORIS weekly solutions, relative to the ITRF2008 origin. GPS weekly solution over the three translation components show a good agreement within 5 mm-in X and Y and about 10 mm average in Z, over the selected processing period 1996–2011. DORIS show their origin agreement being in the range 1–10 mm in X and Y and about 15mm average in Z over the period 1993-2011. Both their scale are in average of 1 ppb.



4. GPS-DORIS PROCESSING AND COMBINATION

AFREF solution generation involved three steps .1) individual daily processing of GPS and DORIS, and combination to weekly loose solution using GAMIT-GLOBK (Herring T, R. W. King, S. C. McClusky. 2010) for GPS and GIPSY-OASIS 5.0 software (Webb and Zumberge 1995;Willis et. al., 2005a) for DORIS . 2) Stacking the individual weekly loose solution to estimate a combined long-term solution per technique using CATREF software, constrained to the ITRF2008 core stations. and 3) Combining the resulting long-term solutions of the GPS and DORIS techniques with their full variance covariance together with the local ties in co-location sites using CATREF to obtain the cumulative solution (position and velocities). The schematic diagram below explain these steps in detail.

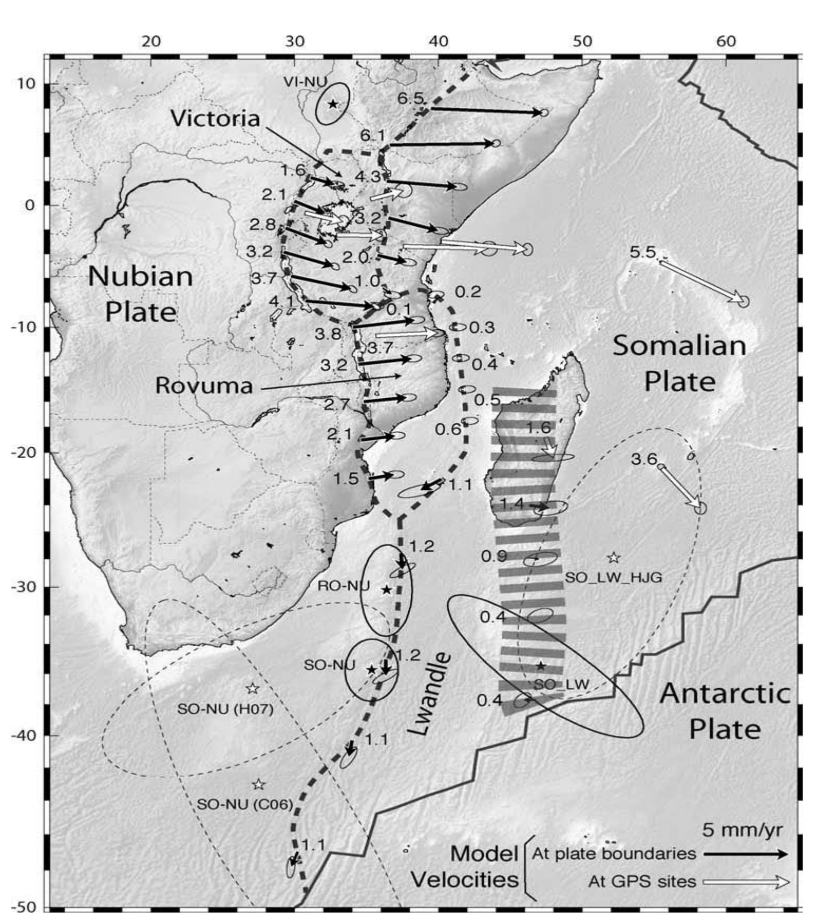


5. ROLE OF TECTONIC IN AFREF REALIZATION

As the unified geodetic reference frame for Africa, AFREF will be the fundamental basis for the national and regional three-dimensional reference networks fully consistent with the International Terrestrial Reference Frame (ITRF). African among all major tectonic plates, has long-resisted investigations of its kinematics due to a lack of geodetic measurements. Currently GPS, DORIS, seismological and geomorphological observations clearly indicate that the African continent is breaking apart along the East African Rift (EAR) into two plates: Nubia to the West and Somalia to the East with an opening rate increasing from 1 to 7 mm/yr from south to North (Nocquet et al, 2006).

Recent work that included more GPS and DORIS data, as well as earthquake slip vectors, spreading rates and transform azimuths provide a more detailed kinematics with three additional sub-plates (Rovuma, Victoria and Lwandle; Calais et al., 2006; Stamps et al., 2008).

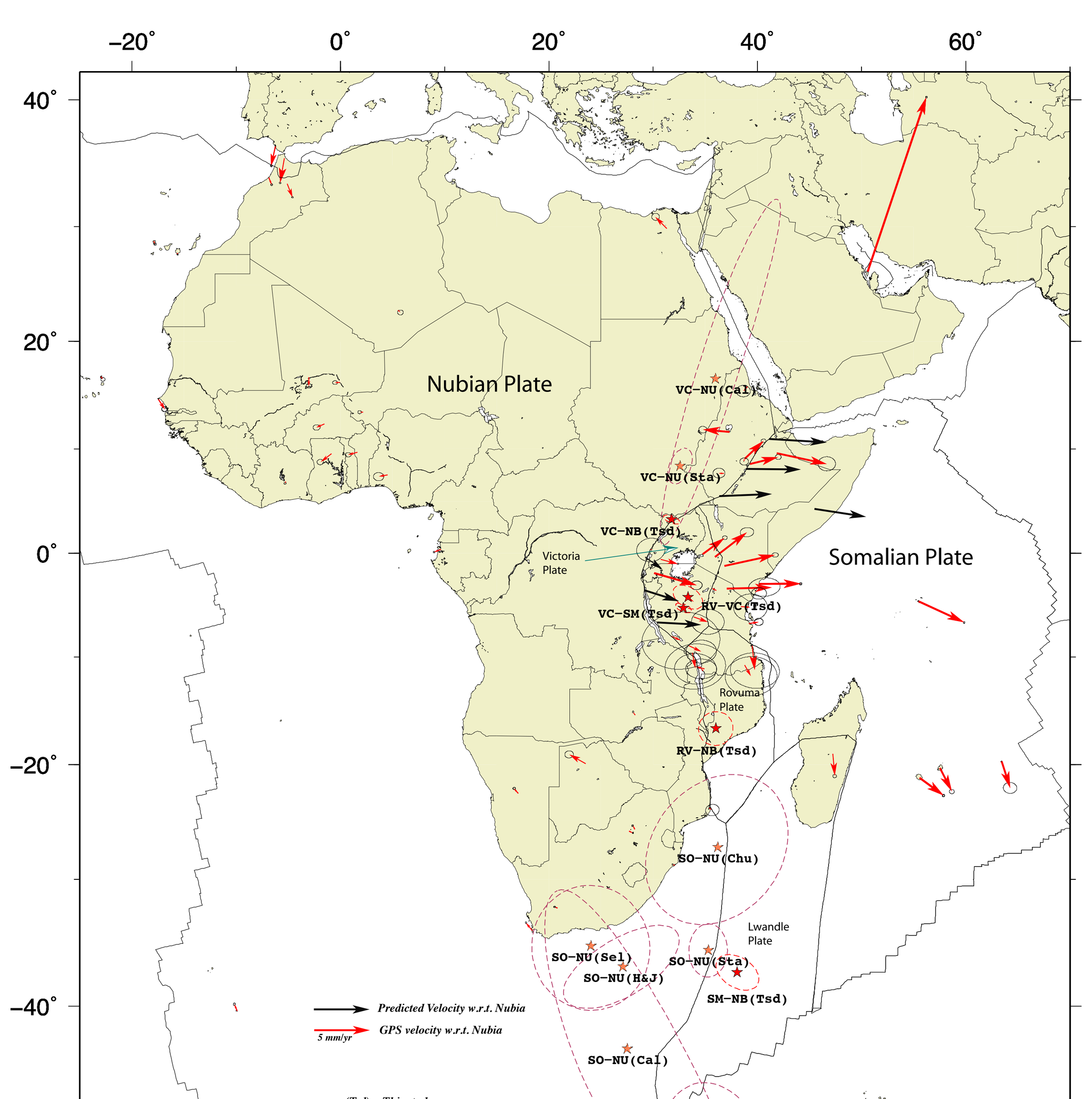
KINEMATIC MODEL OF THE EAR (Stamps et. al., 2008)



6. NUBIAN FIXED FRAME FROM GPS ONLY

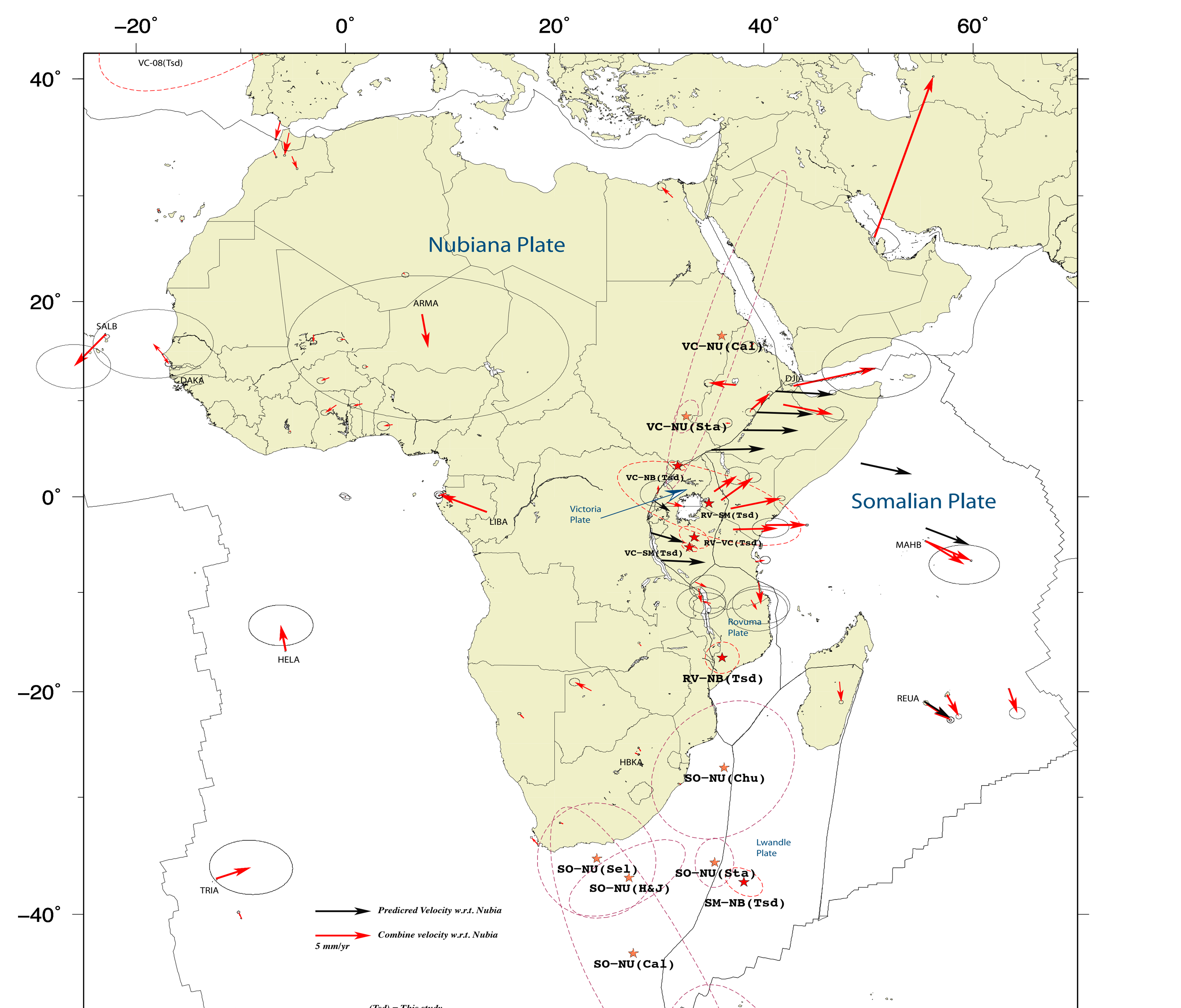
The figure below show GPS velocity solution with respect to Nubia, with only sites whose velocity uncertainties is less than 1.6 mm/yr. This Nubian-fixed frame is defined using 13 sites with high quality, long term time series located on stable Nubia (SUTH, MAS1, SUTM, YKRO, RBAY, HRAO, ZAMB, HARB, GOUG, TAMP, PRE1, LPAL and GMAS). The WRMS for horizontal velocities is 0.2555 and 0.2009 mm/yr in the north and east components respectively.

GPS VELOCITY RELATIVE TO NUBIAN FIXED FRAME



7. NUBIAN FIXED FRAME FROM COMBINED GPS AND DORIS

The figure below show a combined DORIS GPS velocity solution with respect to Nubia, with only sites whose velocity uncertainties is less than 1.6 mm/yr except for some DORIS sites. This Nubian-fixed frame is defined with high quality, long term GPS-DORIS time series located on stable Nubia, using 13 GPS sites (SUTH, MAS1, SUTM, YKRO, RBAY, HRAO, ZAMB, HARB, GOUG, TAMP, PRE1, LPAL and GMAS) and 1 DORIS sites (HBKA). The WRMS for horizontal velocities fit is 0.22 and 0.20 mm/yr in the north and east components respectively.



8. COMPARISON TO PREVIOUS WORKS

Table below shows a list of angular velocities and associated uncertainties estimated for the African plates (Nubia, Somalia, Victoria, Rovuma) and comparisons with previous studies. Angular velocities are in deg/Ma, clockwise is positive. The relative velocity for Somalia-Nubia is obtained including for the first time two campaign GPS site in Tanzania LGDO and HIMO - (USA-NSF Tanzania Project) , two DORIS sites REUA and MAHB , together with IGS sites SEY1, RCMN, MALI, MAL2, REUN, and VACS. The result for this inversion is shown in the table below.

Test_w.r.t.	Plate	Lon	Lat	Semi Major	Semi Minor	WRMS_fit N/E	Ang_vel	Sigma Ang_vel	Study
ITRF2008	Nubia	81.212	50.020	0.246	0.081	0.22 / 0.20	0.2682	0.0005	This-Study
	Somalia	93.631	50.403	0.598	0.329	0.26 / 0.26	0.3159	0.0022	This-Study
	Victoria	-13.560	44.348	8.103	4.125	0.37 / 0.30	0.3120	0.0223	This-Study
	Rovuma	72.226	-43.309	6.559	3.475	0.57 / 0.48	0.3563	0.0424	This-Study
ITRF2005	Nubia	80.395	51.244	4.130	1.558	-	0.2440	0.0004	Stamps et. al., 08
	Somalia	80.970	50.600	1.300	0.680	-	0.2610	0.0030	Calais et. al., 06
Nubia	Somalia	38.105	-37.347	1.003	1.561	0.27 / 0.27	-0.0625	0.0030	This-Study
	Somalia	35.286	-35.719	2.080	1.500	-	0.0880	0.0440	Stamps et. al., 08
	Somalia	27.510	-43.060	13.230	3.590	-	0.0690	0.0130	Calais et. al., 06
	Somalia	36.970	-54.760	9.500	4.600	-	-0.0690	0.0090	Fernandes et. al., 04
	Somalia	24.020	-35.490	4.900	4.600	-	-0.0850	0.0050	Sella et. al.,99
	Somalia	36.200	-27.300	6.090	5.500	-	-0.0890	0.0040	Chu&Gordon, 02
	Victoria	31.769	3.307	0.324	0.824	0.37 / 0.30	0.2245	0.0446	This-Study
	Rovuma	36.039	-16.622	1.590	1.534	0.57 / 0.48	-0.1360	0.0558	This-Study
	Victoria	32.589	8.370	1.800	1.000	-	0.1290	0.0058	Stamps et. al., 08
	Victoria	35.990	16.610	16.550	1.850	-	-0.0750	0.0400	Calais et. al., 06
Somalia	Victoria	32.915	-5.296	0.361	0.813	0.37 / 0.30	0.2747	0.0445	This-Study
	Rovuma	34.775	-0.696	3.308	9.205	0.57 / 0.48	0.0807	0.0543	This-Study
Victoria	Rovuma	33.338	-4.253	0.956	1.559	0.57 / 0.48	0.3552	0.0549	This-Study

9. DISCUSSION AND CONCLUSION

A velocity field for Nubia is estimated in a global consistent reference frame ITRF 2008. We obtained an up-to-date position/velocity solution using data from 100 continuously observing GPS and 9 DORIS sites in Africa, the largest data set ever processed for the continent. We find that the interior of the Nubian plate is rigid to within WRMS of 0.22 and 0.20 mm/yr in the north and east componets respectively. We propose an updated angular velocity for Nubia/Somalia, consistent with the most recent GPS estimate (Stamps et al., 2008) and with the 3.2 million years average (Horner-Johnson et. al., 2007). We confirmed the counter clockwise rotation of the Victoria plate and Rovuma plate with respect to Nubia, using GPS observations only for the first time. The spatial density of the current available GPS and DORIS networks is not sufficient yet to estimate robust angular velocities for a remaining smaller sub-plate (Lwandle) without using additional external geophysical data.

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