Supplement of Hydrol. Earth Syst. Sci. Discuss., 12, 11173–11222, 2015
http://www.hydrol-earth-syst-sci-discuss.net/12/11173/2015/
doi:10.5194/hessd-12-11173-2015-supplement

Hydrology and Earth System Sciences
Open Access
Discussions

Supplement of

Hydrological, chemical and isotopic budgets of Lake Chad: a quantitative assessment of evaporation, transpiration and infiltration fluxes

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Supplementary material

References	Data	Localization	Monitored period	Number of data	Lake state	data processing	strategy of use in our study
		LAKE CHAD (Fig.2)				MODEL CALIBRATION AND VALIDATION	
Bader et al., 2011	lake levels	Southern pool, Northern pool, Archipelagos	1956 - 2008	1132	Normal and Small	unchanged	calibration
Leblanc et al., 2011	surface estimations	Northern Pool	1986-2001	105	Small	unchanged	calibration
Carmouze, 1976	[Na+]	Southern pool - distributed	04/68-01/73	12	Normal	averaged for the Southern pool	calibration
Chantraine and Lemoalle (1976a, 1976b, 1977),	[Na+]	Southern pool - distributed	10/73-03/77	23	Transition	averaged for the Southern pool and corrected	calibration
Carmouze, 1976, 1979	[Na+]	Northern pool - distributed	04/68-01/73	13	Normal	averaged for the Northern pool	calibration
Chantraine and Lemoalle (1976a, 1976b, 1977), Chantraine (1978)	[Na+]	Northern pool - distributed	09/73-04/76	8	Transition	averaged for the Northern pool and corrected	calibration
Carmouze, 1976	[Na+]	Archipelagos - distributed	04/68-01/73	12	Normal	averaged for the Archipelagos	calibration
Chantraine and Lemoalle (1976a, 1976b, 1977), Chantraine (1978)	[Na+]	Archipelagos - distributed	09/73-01/77	18	Transition	averaged for the Archipelagos and corrected	calibration
This study	[Na+]	Southern pool - localized	2008-2011	15	Small	unchanged	validation
Carmouze (1979)	[Na+]	Northern pool - localized	24-mai	2	Normal	unchanged	validation
Chantraine and Lemoalle (1976a, 1976b, 1977), Chantraine (1978)	[Na+]	Northern pool - localized	1974-1975	7	Transition	unchanged	validation
Gaultier, 2004	[Na+]	Northern pool - localized	1999-2001	2	Small	unchanged	validation
Zairi, 2008	[Na+]	Northern pool - localized	2003-2005	37	Small	unchanged	validation
This study	[Na+]	Northern pool - localized	2008	1	Small	unchanged	validation
This study	[Na+]	Archipelagos - localized	2012	8	Small	unchanged	not used
Roche, 1980	$\delta^{18}O$	Southern pool - distributed	09/68-12/69	4	Normal	averaged for the Southern pool	calibration
Roche, 1980	$\delta^{18}O$	Northern pool - distributed	09/68-12/69	4	Normal	averaged for the Northern pool	calibration
Roche, 1980	$\delta^{18}O$	Archipelagos - distributed	09/68-12/69	4	Normal	averaged for the Archipelagos	calibration
Djoret, 2000	$\delta^{18}O$	Southern pool - localized	1971	2	Transition	localized	validation
This study	$\delta^{18}O$, $\delta^{2}H$	Southern pool - localized	2008-2011	13	Small	localized	validation
Djoret, 2000	$\delta^{18}O$	Northern pool - localized	1971	10	Transition	localized	validation
Gaultier, 2004	$\delta^{18}O$, $\delta^{2}H$	Northern pool - localized	1999-2001	2	Small	localized	validation
This study	$\delta^{18}O$, $\delta^{2}H$	Northern pool - localized	2008	1	Small	localized	validation
Djoret, 2000	$\delta^{18}O$	Archipelagos - localized	1971	1	Transition	localized	validation
		RIVERS (Fig.3)				MODEL INPUT VARIABLE	
Bader et al., 2011	daily discharge	Chari-Logone and KY	1956-2011	reconstructed data on all the time period		unchanged	
Carmouze, 1976	[Na+]	Chari-Logone	1976	12			
Roche, 1969	[Na+]	Chari-Logone	1969	12			
Olivry, 1996	[Na+]	Chari-Logone	mean	12		monthly averages >> 1-year monthly scenario	spline interpolation to daily values
Djoret, 2000	[Na+]	Chari-Logone	1995-1996	6			
Zairi, 2008	[Na+]	Chari-Logone	2008-2009	5			
This study	[Na+]	Chari-Logone	2008-2011	12			
Roche, 1969	[Na+]	Komadougou-Yobé	1970	10			
Gaultier, 2004	[Na+]	Komadougou-Yobé	2001-2002	34		monthly averages >> 1-year monthly scenario	spline interpolation to daily values
Zairi, 2008	[Na+]	Komadougou-Yobé	2007-2008	12			
This study	[Na+]	Komadougou-Yobé	2008	1			
Fontes, 1970a	$\delta^{18}O$	Chari-Logone	1967-1969	56		monthly averages >> 1-year monthly scenario	spline interpolation to daily values
Djoret, 2000	$\delta^{18}O$ / $\delta^{2}H$	Chari-Logone	1971-1973 et	46/10			
This study	$\delta^{18}O$ / $\delta^{2}H$	Chari-Logone	2008-2012	07-janv			
Gaultier, 2004	$\delta^{18}O$ / $\delta^{2}H$	Komadougou-Yobé	2001-2002	21/21		monthly averages >> 1-year monthly scenario	spline interpolation to daily values
This study	$\delta^{18}O$ / $\delta^{2}H$	Komadougou-Yobé	2008	1			
		RAINFALL (Fig.4)				MODEL INPUT VARIABLE	
Bader et al., 2011	daily rainfall rates	Southern Pool, Northern Pool, Archipelagos	1956-2011	reconstructed data		unchanged	
Roche, 1980	monthly [Na+]	N'Djaména	1969	12		1-year monthly scenario	spline interpolation to daily values
GNIP, IAEA	$\delta^{18}O$	N'Djaména	1964-1995	86		interannual monthly values reconstructed	spline interpolation to daily values
GNIP, IAEA	$\delta^{2}H$	N'Djaména	1964-1995	74		interannual monthly values reconstructed	spline interpolation to daily values
		ATMOSPHERIC VAPOR (Fig.4)				MODEL INPUT VARIABLE	
Tremoy et al., 2012	delta 18O	Niamey	June 2010 - May 2011	hourly and daily measurements		1-year monthly scenario	spline interpolation to daily values
		CLIMATIC VARIABLES				MODEL INPUT VARIABLE	
Harris et al., 2014, CRU	Temperature	Southern Pool, Northern Pool, Archipelagos	1956-2011	monthly		interannual monthly values	spline interpolation to daily values
Harris et al., 2014, CRU	Relative Humidity	Southern Pool, Northern Pool, Archipelagos	1956-2011	monthly		interannual monthly values	spline interpolation to daily values

Table 1. Details on the data set from the literature used in this study.

Table 2. Details on the new data set provided in this study

Location	Date of sampling	$[Na^+]$ ($mmol.L^{-1}$)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)
Lake Chad, Archipels	04/08/12	0,75		
Lake Chad, Archipels	04/08/12	0,70		
Lake Chad, Archipels	04/08/12	0,61		
Lake Chad, Archipels	04/08/12	0,72		
Lake Chad, Archipels	05/08/12	1,71		
Lake Chad, Archipels	06/08/12	0,74		
Lake Chad, Archipels	06/08/12	0,87		
Lake Chad, Southern pool	17/10/08	0,14	-3,38	-26,6
Lake Chad, Southern pool	02/11/10	0,13	-2,67	-15,9
Lake Chad, Southern pool	03/11/10	0,14	-2,63	-16,8
Lake Chad, Southern pool	03/11/10	0,14	-2,71	-17,2
Lake Chad, Southern pool	03/11/10	0,15	-2,68	-17,3
Lake Chad, Southern pool	02/12/11	0,15		
Lake Chad, Southern pool	03/12/11	0,16	-1,61	-9
Lake Chad, Southern pool	04/12/11	0,15	-1,6	-9,7
Lake Chad, Southern pool	06/12/11	0,15	-1,53	-9,7
Lake Chad, Southern pool	07/12/11	0,15	-1,38	-9,1
Lake Chad, Southern pool	07/12/11	0,15	-1,53	-9,2
Lake Chad, Southern pool	09/12/11	0,16	-1,42	-8,3
Lake Chad, Southern pool	09/12/11	0,15	-1,58	-8,2
Lake Chad, Southern pool	10/12/11	0,15	-1,44	-9
Lake Chad, Southern pool	11/12/11	0,21		
Lake Chad, Northern pool	11/10/08	0,88	9,93	38,60
Chari-Logone	19/10/08	0,13	-3,03	-20,7
Chari-Logone	19/11/11	0,11	-2,18	
Chari-Logone	19/11/11	0,15		
Chari-Logone	20/11/11	0,14	-2,77	
Chari-Logone	20/11/11	0,09	-3,26	
Chari-Logone	20/11/11	0,14		
Chari-Logone	21/11/11	0,19	-2,62	
Chari-Logone	27/11/11	0,14	-2,58	
Chari-Logone	01/12/11	0,15	-1,61	
Chari-Logone	22/07/12	0,13		
Chari-Logone	05/12/12	0,19		
Chari-Logone	04/12/12	0,15		
Komadougou-Yobe	12/10/08	0,21	-3,44	-25,8

Metropolis algorithm steps

This algorithm can be summarized by the following steps :

1. A parameter set is defined by the value of the likelihood function :

$$L(m_i) = k.\exp\left(\frac{-S(\mathbf{m_i})}{li^2}\right) \tag{1}$$

   where where *k* is an appropriate normalization constant and li refers to the total noise variance.

2. At the inversion stage i+1, from a parameter set $\mathbf{m}_i$, a new parameter set $\mathbf{m}_{i+1}$ is randomly created by a perturbation of $\mathbf{m}_i$ within the a priori probability density function. The coefficient of perturbation corresponds to the local exploration of the neighborhood of the current value

of the Markov Chain process. It is chosen as 1/30 of the total range of a priori PDF to ensure exploration of all the parameter space.

3. The direct problem is solved using the model and the parameter set $\mathbf{m}_{i+1}$ and the new misfit S($\mathbf{m}_{i+1}$) is calculated. The probability to accept the displacement from $\mathbf{m}_i$ to $\mathbf{m}_{i+1}$ is calculated using:

$$p = 1 \qquad if S(\mathbf{m_{i+1}}) < S(\mathbf{m_i}) \tag{2}$$

$$p = \exp\left(\frac{-(S(\mathbf{m_{i+1}}) - S(\mathbf{m_i}))}{li^2}\right) \qquad if S(\mathbf{m_{i+1}}) > S(\mathbf{m_i}) \tag{3}$$

In the second unfavorable case, in practice, a number n is sorted in a uniform distribution between 0 and 1. It n is lower than the p value in Eq. 3, which has the probability p of occuring, then the unfavorable displacement to $\mathbf{m}_{i+1}$ is accepted. The probability to accept a displacement that increases the error between the model and the data is designed to leave local minima of the misfit function (Eq **??**). The li value influences the probability to accept an unfavorable case and must be chosen as a trade-off between avoidance of local minima and divergence of the misfit function. Several values of li were tested and a value of 0.03 was used.

4. Those steps are repeated until convergence is reached.

5. At the end, this method yields many parameter sets that were used during the walk. Only those that match a convergence criteria are kept (Fig. 1). The values of the parameters kept are analyzed to obtain the marginal *a posteriori* PDF of each parameter.

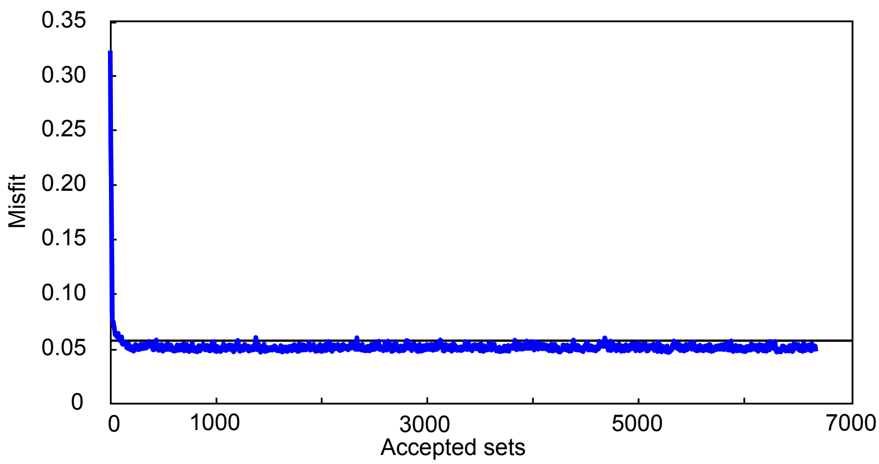

Figure 1. Representation of the misfit function as a function of the accepted samples during the Metropolis random walk algorithm.