Relationships between CO_2 flux estimated by inverse analysis and land surface elements in South America and Africa

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Introduction :

Inverse analysis estimates the regional flux of greenhouse gases between the earth's surface and the atmosphere by using observed atmospheric concentration data that include satellite data. In particular, this method is effective in estimating the flux in regions where observational flux data are limited. However, inverse analysis is basically a mathematical optimization method. Therefore, confirmation of the causal validity of the spatial and temporal changes in the estimated flux is necessary. One confirmation method is validation of the relationship with physical and biological observation data (analysis data) of confirmed accuracy. In this study, the features and validity of changes in the carbon dioxide (CO_2) flux estimated by inverse analysis were verified by interrelation analysis with changes in precipitation, short-wave radiation, surface temperature, and Normalized Difference Vegetation Index (NDVI) in regions of South America and Africa where CO_2 flux observation data are limited.

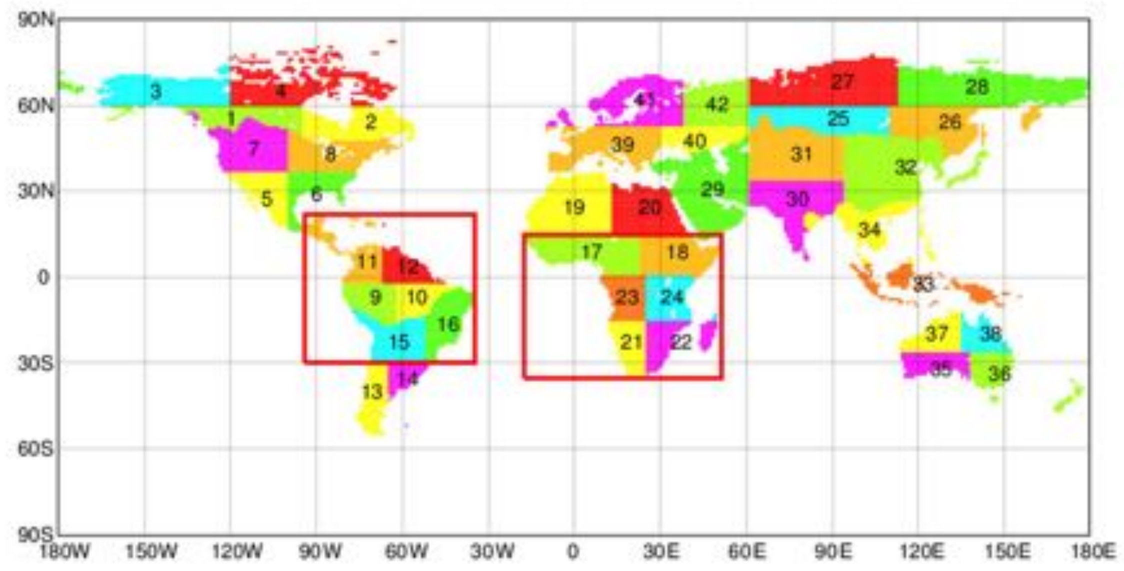

Fig. 1. The analyzed regions are Regions 9, 10, 11, 12, 15, and 16 in South America, and Regions 17, 18, 21, 22, 23, and 24 in Africa.

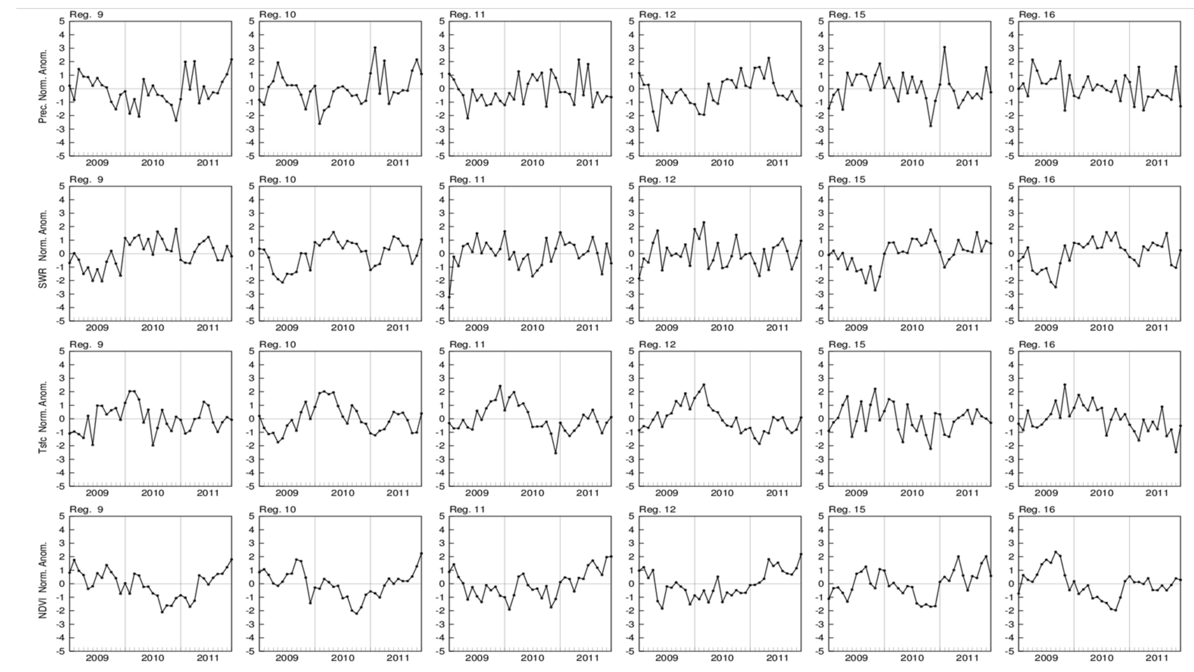

Fig. 2. Time series of normalized anomaly of the following land surface elements in South America: precipitation (the top panels), short-wave radiation (the second panels), surface temperature (the third panels), and the Normalized Difference Vegetation Index (NDVI) (the bottom panels). In each six panels group, the leftmost panel is for Region 9, the second is for Region 10, the third is for Region 11, the fourth is for Region 12, the fifth is for Region 15, and the rightmost panel is for Region 16.

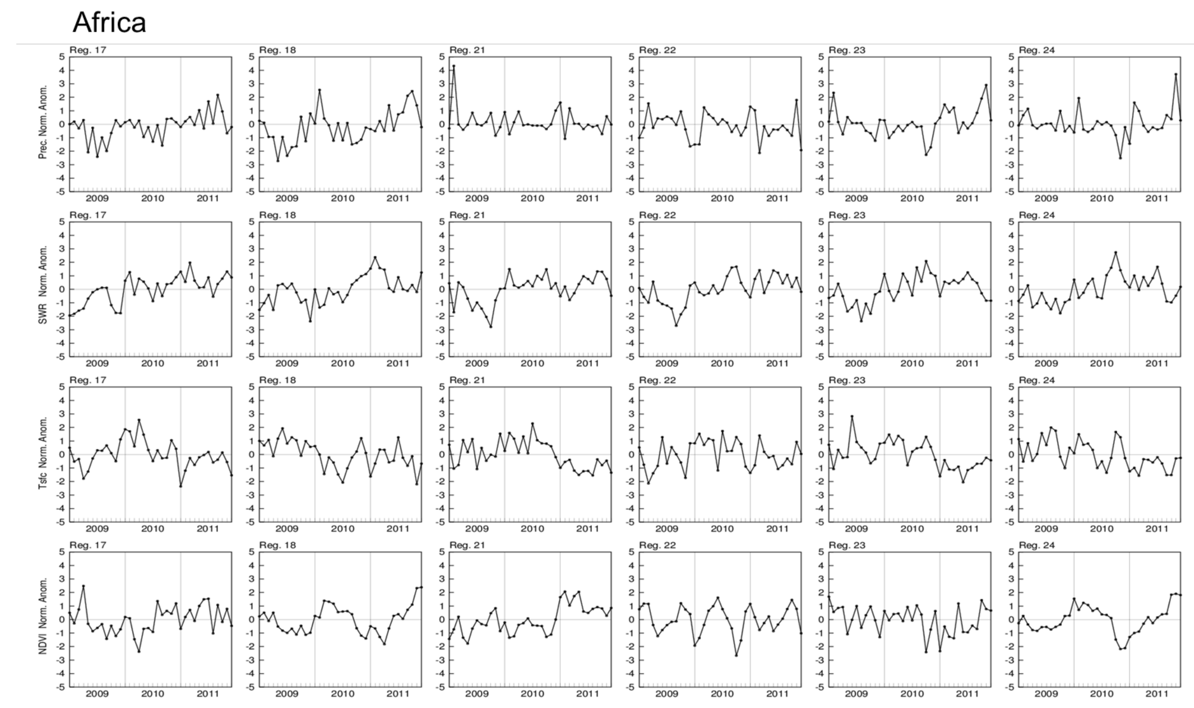

Fig. 3. The same as in Fig. 2, except for Africa. In each six panels group, the leftmost panel is for Region 17, the second is for Region 18, the third is for Region 21, the fourth is for Region 22, the fifth is for Region 23, and the rightmost panel is for Region 24.

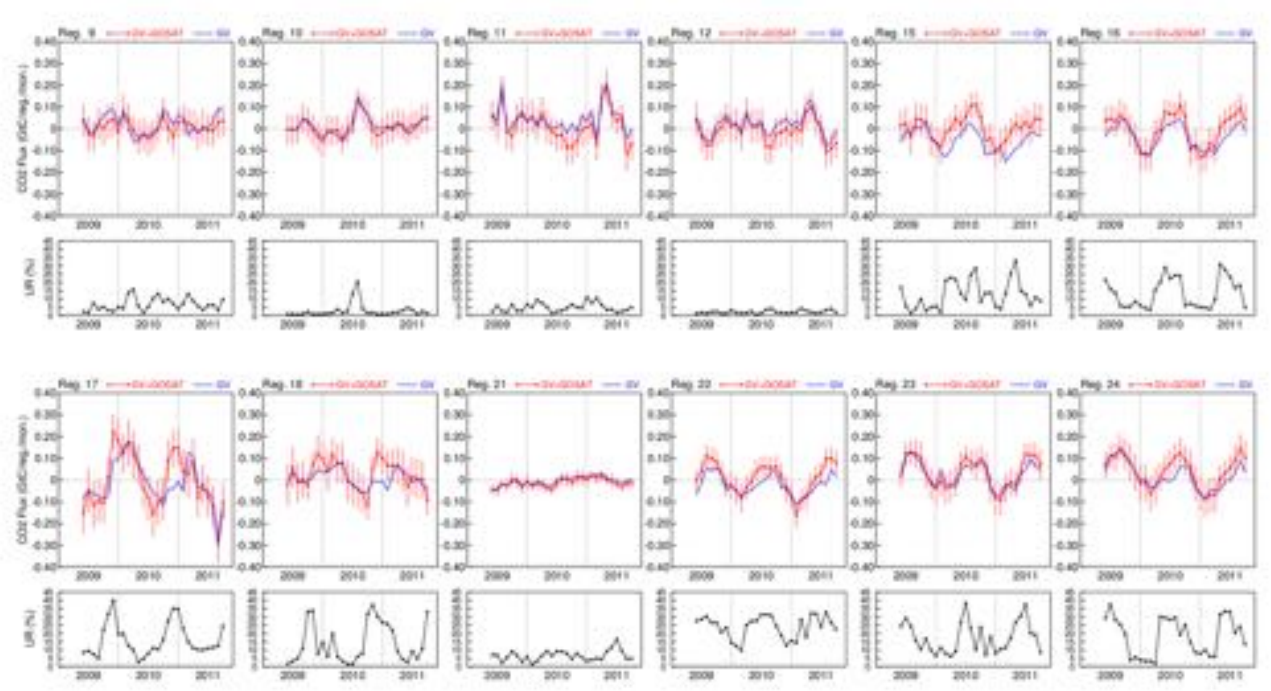

Fig. 4. Time series of the carbon dioxide (CO_2) flux (GtC region^{-1} month^{-1}) and the uncertainty reduction (UR) (%). The top panels are the CO_2 flux values in South America and the second panels are the UR values in South America. The third panels are the CO_2 flux values in Africa and the bottom panels are the UR values in Africa. For CO_2 flux, downward flux (from the atmosphere to the land surface) is negative and upward flux is positive. The placement of panels for six regions is the same as that of each six panels group in Fig. 2 (for South America) and Fig. 3 (for Africa). In the panels for CO_2 flux, red lines indicate the CO_2 flux values by inverse analysis that used GLOBALVIEW-CO_2 ground-based data (GV) and the Greenhouse gases Observing SATellite (GOSAT) column-averaged mole fractions of CO_2 (XCO_2) data (GOSAT). Vertical red bars indicate the uncertainty values for each monthly CO_2 flux by inverse analysis that used GV and GOSAT data. Blue lines indicate CO_2 flux values by inverse analysis that used only GV data.

Conclusions :

The accuracy of the land surface elements is required for the adequacy of the analysis to confirm the accuracy of the CO_2 flux. An examination of the correlation of anomalies showed consistent relationships among the precipitation, short-wave radiation, surface temperature, and NDVI data used in this study, which were created independently.

The relationships between change in the estimated CO_2 flux and characteristic changes of the land surface elements in South America and Africa were consistent in each region. This study confirmed the physical and biological validity of the changes in the CO_2 flux estimated by inverse analysis.

During the period of this study, the NDVI anomaly was influential in South America, and the precipitation (soil wetness) anomaly was an essential factor in Africa for the CO_2 flux anomaly. The short-wave radiation anomaly was also influential at the inverse analysis region scale in both South America and Africa.

The distinctive relationships are detected more clearly in the results of inverse analysis using both ground-based CO_2 concentration data and the Greenhouse gases Observing SATellite (GOSAT) data than in the results using only ground-based CO_2 concentration data. This demonstrates the usefulness of GOSAT data in regions in which atmospheric CO_2 concentration data are limited.

Table 1. Correlation coefficients between normalized anomaly of precipitation (PREC) and those of other land surface elements (NDVI: Normalized Difference Vegetation Index, SWR: short-wave radiation, and Tsfc: surface temperature) in each region in South America and Africa. The analyzed period is from January 2009 to December 2011. PREC-SWR, PREC-Tsfc, and PREC-NDVI are the correlations between the precipitation and the short-wave radiation, surface temperature, and NDVI, respectively. SEASONAL indicates the correlation among 12 seasons of data over three years. (Each season datum is the three-month mean and the four seasons in each year cover January–March, April–June, July–September, and October–December.) MONTHLY indicates the correlation among 36 months of data over three years. Correlation coefficient values in bold indicate values that exceed the 90% significance level.

		PREC-SWR		PREC-Tsfc		PREC-NDVI	
		SEASONAL	MONTHLY	SEASONAL	MONTHLY	SEASONAL	MONTHLY
S. America	9	**-0.51**	**-0.44**	-0.35	**-0.37**	0.48	0.20
	10	**-0.56**	**-0.44**	**-0.76**	**-0.66**	0.26	0.12
	11	**-0.65**	**-0.54**	-0.47	**-0.32**	0.17	0.07
	12	**-0.69**	**-0.69**	**-0.70**	**-0.65**	0.25	0.15
	15	**-0.65**	**-0.53**	0.32	0.14	0.39	**0.29**
	16	**-0.62**	**-0.49**	0.11	-0.24	0.43	**0.28**
Africa	17	0.22	0.21	-0.11	0.03	0.45	**0.40**
	18	-0.04	-0.19	-0.48	**-0.34**	**0.55**	**0.36**
	21	-0.14	**-0.46**	-0.08	-0.20	-0.16	-0.03
	22	-0.43	**-0.32**	-0.20	-0.25	0.41	**0.38**
	23	-0.31	-0.23	**-0.53**	**-0.36**	0.31	0.14
	24	-0.48	**-0.30**	-0.39	-0.17	**0.71**	**0.39**

Table 2. Correlation coefficients of the temporal changes of normalized anomaly of precipitation between the six regions in each of South America and Africa. The analyzed period is from January 2009 to December 2011. SEASONAL and MONTHLY are the same as in Table 1. The labels 2009, 2010, and 2011 indicate the correlations for 12 months of data for that year. Correlation coefficient values in bold indicate values that exceed the 90% significance level.

			Africa					
			17	18	21	22	23	24
South America	9	SEASONAL	-0.26	-0.03	0.11	0.32	**0.85**	**0.64**
		MONTHLY	**-0.29**	-0.24	-0.24	0.15	**0.46**	**0.32**
		2009	-0.38	-0.48	-0.29	0.40	0.06	0.10
		2010	**-0.64**	-0.44	-0.29	0.16	0.18	-0.08
		2011	-0.49	-0.40	-0.37	0.05	**0.53**	0.46
	10	SEASONAL	-0.14	-0.09	-0.11	0.29	**0.68**	0.43
		MONTHLY	-0.23	-0.20	-0.13	**0.31**	**0.57**	0.27
		2009	**-0.58**	**-0.60**	-0.26	0.35	-0.02	-0.18
		2010	-0.41	**-0.64**	0.20	0.10	0.37	-0.28
		2011	-0.49	-0.28	-0.20	**0.55**	**0.75**	0.48
	11	SEASONAL	0.20	-0.03	0.30	0.06	-0.06	-0.28
		MONTHLY	**0.35**	0.16	0.15	-0.10	-0.11	-0.16
		2009	**0.68**	**0.50**	0.33	-0.24	0.32	0.26
		2010	-0.17	-0.17	0.17	0.05	0.25	-0.17
		2011	**0.51**	0.15	0.05	-0.09	**-0.54**	-0.23
	12	SEASONAL	0.15	-0.11	0.31	-0.01	0.12	-0.22
		MONTHLY	0.25	0.05	0.12	-0.09	0.02	-0.14
		2009	0.39	**0.56**	0.29	-0.02	0.11	0.41
		2010	-0.09	**-0.65**	0.13	0.01	-0.13	**-0.58**
		2011	0.04	-0.25	-0.01	-0.12	-0.22	-0.16
	15	SEASONAL	-0.47	-0.11	-0.15	0.32	0.25	0.43
		MONTHLY	**-0.44**	-0.18	-0.14	0.27	**0.33**	**0.48**
		2009	**-0.51**	-0.35	-0.21	-0.02	-0.05	-0.33
		2010	**-0.64**	0.18	-0.30	0.08	0.42	**0.72**
		2011	-0.31	-0.32	-0.06	**0.56**	**0.60**	**0.64**
	16	SEASONAL	**-0.53**	**-0.69**	0.09	**0.63**	-0.22	-0.17
		MONTHLY	**-0.28**	-0.13	**0.35**	0.23	0.04	0.17
		2009	-0.21	0.11	0.10	0.02	0.02	0.12
		2010	0.04	-0.18	0.47	**0.60**	0.20	0.05
		2011	-0.12	0.19	**0.73**	0.17	0.27	0.39

Table 3. Correlation coefficients of the differences in the CO_2 flux. The monthly difference values between 2009 and 2010 (2010 – 2009) were calculated for a period of seven months from June to December and the values between 2010 and 2011 (2011 – 2010) were calculated for a period of 10 months from January to October. The correlations between the difference values in the six regions in each of South America and Africa were examined. G+G indicates coefficient values for the difference in the CO_2 flux by inverse analysis using GV and GOSAT data. G means those using only GV data. Correlation coefficient values in bold indicate values that exceed the 90% significance level.

			Africa					
			17	18	21	22	23	24
South America	9	G+G	-0.06	-0.10	-0.37	-0.08	0.08	0.23
		G	**-0.44**	**0.42**	**-0.45**	-0.21	0.06	**0.45**
	10	G+G	-0.17	**-0.64**	**0.61**	**-0.53**	**-0.52**	-0.13
		G	0.07	**-0.62**	**0.64**	-0.27	**-0.57**	**-0.62**
	11	G+G	-0.11	0.23	-0.04	0.09	0.11	-0.01
		G	-0.33	0.15	0.05	0.16	0.07	0.29
	12	G+G	**-0.43**	**-0.49**	**0.42**	-0.01	-0.08	0.08
		G	-0.05	**-0.48**	**0.65**	-0.06	-0.25	-0.38
	15	G+G	-0.00	**-0.46**	**0.41**	-0.37	**-0.51**	-0.04
		G	0.09	-0.15	0.17	0.21	**-0.55**	-0.38
	16	G+G	-0.18	-0.32	-0.09	0.17	-0.11	0.20
		G	0.15	-0.21	0.17	0.20	**-0.42**	-0.38

Table 4. Correlation coefficients between the monthly differences in the carbon dioxide (CO_2) flux and in the land surface elements (PREC: precipitation, NDVI: Normalized Difference Vegetation Index, SWR: short-wave radiation, and Tsfc: surface temperature) in each region in South America and Africa. The correlations for the differences between 2009 and 2010 (2010 – 2009) (from June to December) and those for the differences between 2010 and 2011 (2011 – 2010) (from January to October) are examined separately. G+G and G are the same as in Table 3. Correlation coefficient values in bold indicate values that exceed the 90% significance level.

			G+G		G	
			2010-2009 (Jun-Dec)	2011-2010 (Jan-Oct)	2010-2009 (Jun-Dec)	2011-2010 (Jan-Oct)
South America	PREC	9	0.62	-0.54	0.63	-0.29
		10	-0.08	0.19	-0.14	0.28
		11	0.01	0.22	0.04	0.30
		12	0.19	0.54	0.45	**0.74**
		15	0.56	0.30	**0.80**	**0.76**
		16	**-0.70**	**0.77**	-0.25	0.53
	NDVI	9	-0.61	0.10	-0.48	0.43
		10	-0.30	-0.53	-0.18	-0.45
		11	-0.30	-0.51	-0.38	**-0.60**
		12	-0.65	0.21	**-0.89**	0.10
		15	-0.38	-0.09	0.20	0.19
		16	-0.64	0.32	-0.25	0.08
	SWR	9	-0.60	0.36	-0.50	0.12
		10	0.34	-0.47	0.28	-0.43
		11	0.09	0.10	0.18	0.19
		12	-0.62	-0.02	**-0.75**	-0.26
		15	-0.37	-0.14	**-0.76**	-0.45
		16	**0.82**	-0.45	0.59	**-0.58**
	Tsfc	9	-0.45	**0.57**	-0.59	0.29
		10	-0.05	**-0.75**	-0.17	**-0.74**
		11	-0.21	0.35	-0.34	0.08
		12	0.18	-0.16	-0.15	-0.44
		15	0.24	-0.18	0.52	-0.46
		16	0.46	-0.30	0.41	-0.33
Africa	PREC	17	-0.52	-0.50	-0.15	-0.34
		18	0.24	0.28	0.30	**0.58**
		21	**0.75**	-0.14	0.44	-0.05
		22	0.01	-0.49	0.38	**-0.60**
		23	-0.23	-0.33	-0.33	-0.40
		24	-0.04	**0.58**	-0.57	0.30
	NDVI	17	-0.31	-0.29	-0.58	0.00
		18	-0.13	**0.63**	0.13	0.38
		21	0.50	0.46	0.60	**0.59**
		22	0.51	0.06	0.62	-0.54
		23	-0.14	-0.17	-0.34	-0.20
		24	0.45	**0.65**	-0.40	0.33
	SWR	17	-0.00	-0.28	-0.57	0.15
		18	0.19	-0.21	-0.23	**-0.77**
		21	**-0.69**	-0.32	-0.48	-0.44
		22	-0.56	-0.37	-0.42	0.23
		23	-0.15	0.18	-0.20	-0.04
		24	0.24	**-0.66**	0.19	-0.23
	Tsfc	17	**0.72**	0.04	0.49	0.26
		18	-0.21	-0.14	-0.29	0.32
		21	0.05	0.15	0.11	0.21
		22	-0.19	0.32	-0.63	0.43
		23	-0.43	0.34	-0.07	0.29
		24	-0.27	0.03	0.55	0.49

Table 5. The same as in Table 4 except that the correlations are examined for all the regions South America and Africa.

		G+G		G	
		2010-2009 (Jun-Dec)	2011-2010 (Jan-Oct)	2010-2009 (Jun-Dec)	2011-2010 (Jan-Oct)
S. America	PREC	**-0.26**	0.19	0.08	**0.30**
	NDVI	**-0.46**	**-0.24**	-0.20	**-0.23**
	SWR	**0.36**	0.00	-0.01	-0.06
	Tsfc	0.17	-0.08	0.21	-0.19
Africa	PREC	0.04	**-0.23**	0.05	-0.18
	NDVI	0.03	0.15	-0.04	0.12
	SWR	-0.00	-0.19	-0.09	-0.16
	Tsfc	0.11	0.04	0.18	0.12

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