SAFARI 2000 Kalahari Transect CO_2, Water Vapor, and Heat Flux, Wet Season 2000

Abstract

Short-term measurements of carbon dioxide, water, and energy fluxes (30 minute averages) were collected at four locations along a mean annual precipitation gradient in southern Africa during the SAFARI 2000 wet (growing) season campaign of 2000. The purpose of this research was to determine how observed vegetation-atmosphere exchange properties are functionally related to long-term climatic conditions. This research was conducted along the Kalahari Transect (KT), one in the global set of International Geosphere-Biosphere Programme (IGBP) transects, which covers a north-south aridity gradient, all on a homogenous sand formation. Eddy covariance instruments were deployed on a permanent tower in Mongu, Zambia (879 mm of rainfall per year), as well as on a portable tower in Maun (460 mm/yr), Okwa River Crossing (407 mm/yr), and Tshane (365 mm/yr), Botswana for several days at each site.

Background Information

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Project: SAFARI 2000/SAVE

Data Set Title: SAFARI 2000 Kalahari Transect CO_2, Water Vapor, and Heat Flux, Wet Season 2000

Site: Kalahari Transect
 Westernmost Longitude: 21.713
 Easternmost Longitude: 23.594
 Northernmost Latitude: -15.438
 Southernmost Latitude: -24.164

Data Set Citation:

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Data File Information

The data files are stored as ASCII text files, one file per site, in comma-separated-value (csv) format, with column headers. The data files are named:

co2_wve_ghanzi_2000.csv
co2_wve_maun_2000.csv
co2_wve_mongu_2000.csv
co2_wve_tshane_2000.csv

Each file contains the following parameters. The first record in each file contains the column names defined below, followed by subsequent records of data values.

Column Name	Description	Units
Date	Decimal Date, Year 2000	fractional days
Rswin	Shortwave incoming radiation, measured by CRN-1 radiometer	$W m^{-2}$
Rswout	Shortwave outgoing radiation, measured by CRN-1 radiometer	$W m^{-2}$
Rlwin	Longwave incoming radiation, measured by CRN-1 radiometer	$W m^{-2}$
Rlwout	Longwave outgoing radiation, measured by CRN-1 radiometer	$W m^{-2}$
Net_Rad	Net Radiation, Rswin+Rlwin-Rswout-Rlwout	$W m^{-2}$

H	Sensible heat flux, measured in eddy covariance mode by CSAT-3 sonic anemometer, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	W m^{-2}
LE_KH2O	Latent heat flux, measured in eddy covariance mode by CSAT-3 sonic anemometer, in conjunction with a krypton hygrometer, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	W m^{-2}
LE_licor	Latent heat flux, measured in eddy covariance mode by CSAT-3 sonic anemometer, in conjunction with an open path infrared CO_2/H_2O gas analyzer, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	W m^{-2}
G1	Soil heat flux, measured by model HFT3 soil heat flux plates, of bare soil patch at depth of 5 cm	W m^{-2}
G2	Soil heat flux, measured by model HFT3 soil heat flux plates, of vegetated patch at depth of 5 cm	W m^{-2}
IRT1	Infrared surface skin temperature, measured by model IRTS-S infrared thermometers (Mongu - aimed from top of tower at surface; Maun - aimed at vegetated patch; Ghanzi - aimed at combination vegetated/ bare soil; Tshane - aimed at vegetated patch)	degrees C

IRT2	Infrared surface skin temperature, measured by model IRTS-S infrared thermometers (Mongu - not measured; Maun- aimed at combination vegetated/bare soil; Ghanzi - aimed at bare soil; Tshane - aimed at bare soil)	degrees C
IRT3	Infrared surface skin temperature, measured by model IRTS-S infrared thermometers (Mongu - not measured; Maun - aimed at bare soil; Ghanzi - aimed at vegetated patch; Tshane - aimed at combination vegetated/ bare soil)	degrees C
Tsoil1	Soil temperature at depth of 7.5 cm for vegetated patch, as measured by soil thermocouples. At the Mongu site, these data were provided by Pinhiero and Privette (2004) and were measured at a depth of 5 cm (107L Campbell Scientific).	degrees C
Tsoil2	Soil temperature at depth of 2.5 cm for vegetated patch, as measured by soil thermocouples	degrees C
Tsoil3	Soil temperature at depth of 7.5 cm for bare soil patch, as measured by soil thermocouples)	degrees C
Tsoil4	Soil temperature at depth of 2.5 cm for bare soil patch, as measured by soil thermocouples	degrees C
theta1	Volumetric soil moisture, averaged over a depth of 0-30 cm, measured by time domain reflectometry (TDR) for a vegetated patch	unitless
theta2	Volumetric soil moisture, averaged over a depth of 0-30 cm, measured by time domain reflectometry (TDR) for a bare soil patch	unitless
zeta	Atmospheric stability parameter	unitless

air_temp	Air temperature measured by model HMP45C temperature and relative humidity sensor, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	degrees C
RH	Relative humidity measured by model HMP45C temperature and relative humidity sensor, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	percent
wind_speed	Wind speed measured by CSAT-3 sonic anemometer, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	m s^{-1}
Ustar	Friction velocity measured by CSAT-3 sonic anemometer, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	m s^{-1}
wind_dir	Wind angle, measured by CSAT-3 sonic anemometer, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	radians
CO2_conc	CO_2 concentration measured by open path infrared CO_2/H_2O gas analyzer at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	mg m^{-3}
WV_conc	Water vapor concentration, measured by open path infrared CO_2/H_2O gas analyzer at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	g m^{-3}

r2_WV/CO2	Correlation coefficient between CO_2 and water vapor concentrations, measured by open path infrared CO_2/H_2O gas analyzer at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	unitless
CO2_flux	Carbon dioxide flux, measured in eddy covariance mode by CSAT-3 sonic anemometer, in conjunction with an open path infrared CO_2/H_2O gas analyzer, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	µmol m^{-2} s^{-1}
VPD	Vapor pressure deficit derived from air temperature and relative humidity measurements made by model HMP45C, at heights of 31.2 m for Mongu, 10.4 m for Maun, 5.1 m for Ghanzi, and 10.4 m for Tshane	mb
WUE	Water use efficiency, divide Carbon dioxide flux by Latent heat flux and convert units	mg CO_2 (g $H_2O)^{-1}$
Photosyn	Photosynthesis energy, convert Carbon dioxide flux to units of energy flux	W m^{-2}
PPFD	Photosynthetic photon flux density, taken as 0.475* 2 Rswin, with units conversion	µmol m^{-2} s^{-1}

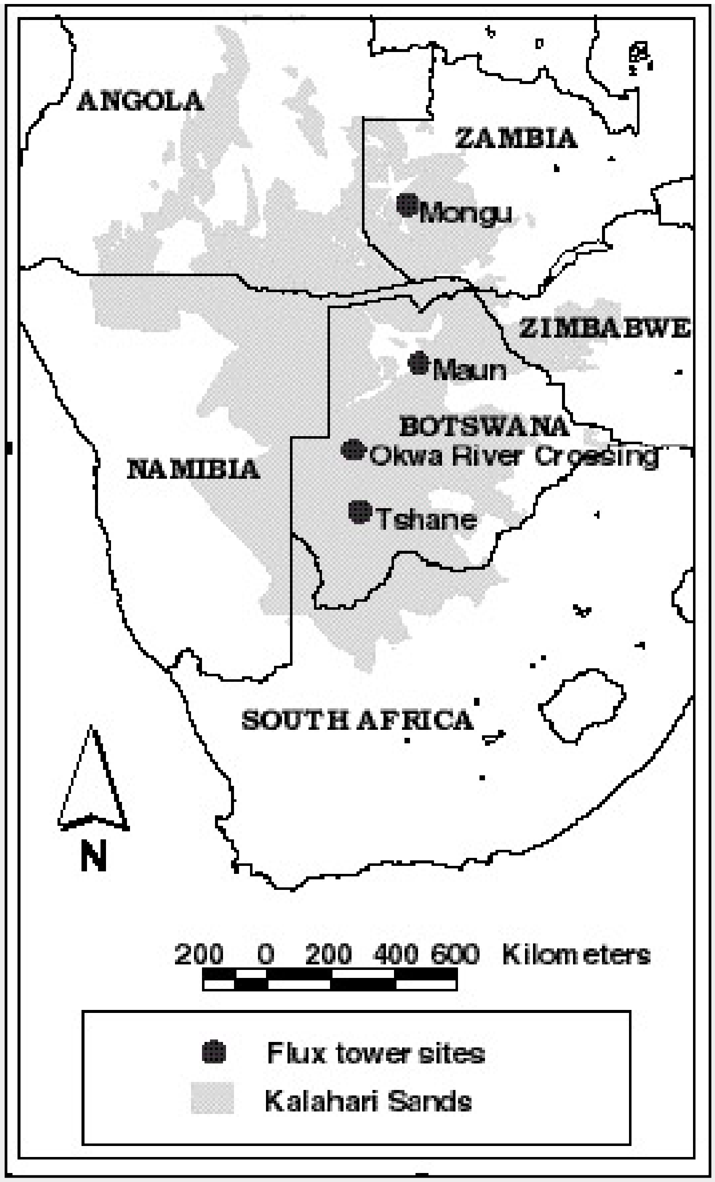
Site Descriptions

Flux measurements were taken during the SAFARI 2000 wet season campaign at four locations along a portion of the Kalahari Transect (KT) extending from Mongu, Zambia in the north to Tshane, Botswana in the south (see map below). The field sites are referenced by their nearest geographical designation: Mongu, Maun, Okwa River Crossing (ORC), and Tshane, although the actual field sites were established tens of kilometers from the towns in order to avoid significant anthropogenic influences. This portion of the KT extends over 8.5° in latitude and covers a gradient in average annual precipitation from 879 mm in Mongu to 365 mm in Tshane. Vegetation type and structure reflect this climate gradient, which covers a range in vegetation composition from broadleaf evergreen forest in the north to open savanna in the south (Scholes et al., 2002).

Table 1. Site locations along the Kalahari transect, wet season 2000.

Site	Observation Period	Location	Elevation [m]	Average Rainfall [mm]
Mongu	Feb 29 - Mar 10	15.438°S 23.253°E	1052	879
Maun	Mar 4 - Mar 9	19.923°S 23.594°E	900	460
Okwa River Crossing (Ghanzi)	Mar 10 - Mar 13	22.409°S 21.713°E	1131	407
Tshane	Mar 15 - Mar 16	24.164°S 21.89° E	1118	365

Note: Rainfall values for Mongu, Okwa River Crossing, and Tshane sites are from a rain gauge network.



Map of southern Africa, showing the location of the flux measurement sites along the Kalahari Transect. A homogeneous aeolian sand formation (shaded) is present at all of the sites, as well as over a large portion of the region.

Table 2. Vegetative characteristics of sites along the Kalahari transect, with LAI, fractional cover, and albedo measured during the wet season field campaign of 2000.

Site	Vegetation Cover	Dominant Species	Canopy Height [m]	LAI	Fraction-al Cover	Al-bedo
Mongu	Kataba forest	*Brachystegia spiciformis*	11	1.67	0.648	0.123
Maun	Mopane woodland	*Colophospermum mopane*; *Terminalia sericea* thicket	9.35	1.21	0.361	0.172
Okwa River Crossing (Ghanzi)	Open shrubland w/ scattered trees	*Acacia mellifera*; *Grewia flava*	1.5	0.61	0.321	0.175
Tshane	Open savanna	*Acacia luederitzii*; *Acacia mellifera*	7	0.77	0.138	0.225

Note: Canopy Height defined as the mean of the top 10% vegetation height, from Scholes et al. (2002); LAI from Tracing Radiation and Architecture in Canopies (TRAC) measurements by Privette et al. (2002).

Materials and Methods

Two sets of micrometeorological instruments were used during the field campaign, the first of which was mounted at a height of 31.2 m on a permanent tower in Mongu, at approximately three times the mean canopy height of 11.0 m. A second set of instruments was transported along the transect for use with a portable tower, designed for rapid deployment and having telescopic height adjustment (model T-35H, Aluma Tower Company, Inc., Vero Beach, Florida). There was some overlap in the periods of measurement, with the Mongu tower maintaining operation during the time of the portable flux tower deployment at Maun. The instrumention used on these towers are listed in Table 3.

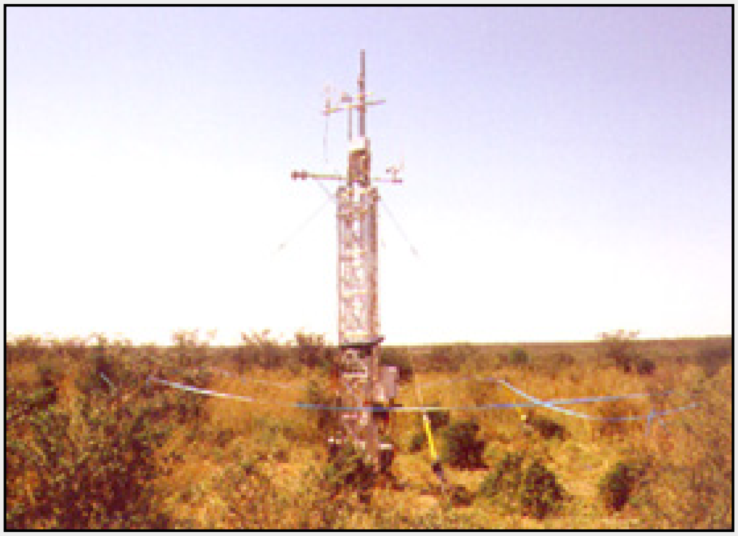
Photographs of the study sites are shown below. Additional photographs (.jpg) that complement the experimental descriptions for this data set are available on the

S2K Photo Gallery pages.

Maun tower setup.

Tshane tower site.

Radiometer above Mongu canopy tower.


Measurement tower at Ghanzi site.

Measurements at the Mongu tower commenced on February 29, 2000, during the height of the southern African wet (growing) season. Sensible heat, latent heat, and CO_2 fluxes were measured with a triaxial sonic anemometer in conjunction with an open path infrared CO_2/H_2O gas analyzer. A krypton hygrometer was used at the Mongu site for comparison with the water vapor concentration fluctuations measured by the Li-7500. The eddy covariance measurements were taken at a frequency of 10 Hz and the turbulent fluxes were recorded on a data logger as half-hour averages. In addition to the eddy covariance measurements, the individual components of net radiation were measured along with temperature and relative humidity at one-minute intervals, then averaged over the half-hour periods. Soil temperature, heat flux, and moisture content were measured near the base of the tower (Pinheiro and Privette, 2004). PAR was taken as a constant fraction of the incoming shortwave radiation (400-1100 nm wavelength range). Bégué et al. (1996) found this fraction to be consistent at 0.475 during the wet season in western Africa, and this value is used in the present study. Photosynthetically active radiation (PAR) was later converted to a photosynthetic photon flux density. A tipping bucket rain gauge was used to measure precipitation. Data were collected over a period of 12 days at Mongu, with episodes of missing data attributable to temporary losses of the anemometer signal from rain or condensation on the sensor. Loss of battery power at the temporarily-instrumented Mongu tower ultimately resulted in the cessation of the measurements at this location.

The portable flux tower was similarly instrumented, only with the omission of a krypton hygrometer and the addition of ground instrumentation. Soil moisture was averaged over a depth of 0-30 cm with time domain reflectometry (TDR) at two locations at each site that were representative of bare soil and vegetated patches. Other ground instruments that were used at the portable tower field sites were soil heat flux plates, soil thermocouples, and infrared thermometers which detected the skin temperature of the vegetation and soil. The portable flux tower was first used in Maun and was extended to its highest position, 10.4 m, to make measurements above the sparse canopy with the mean height of the tallest 10% of trees being 9.4 m. The tower operated for all or part of 6 consecutive days at this location. Next, the tower was transported to ORC, where it was set at a height of 5.1 m, above the shrubby vegetation with an average height of 1.5 m. Since the dimensions of the sensor footprint are a function of the height of the sensor above the displacement height (e.g., Schuepp et al., 1990), the investigators chose to limit the footprint area to an area that was representative of the overall vegetation community by reducing sensor height from its fully-extended position. Finally, the portable tower was moved to Tshane, where once again it was set at its maximum height, above the 7.0 m canopy. Although the flux measurements were scheduled to be taken over a 4-day period, as at ORC, a passing thunderstorm cut the experiment short by disabling the eddy covariance system after one full day of measurements.

Table 3: Fixed and Portable tower instrumentation

Instrument	Model	Manufacturer
sonic anemometer	model CSAT-3	Campbell Scientific, Inc., Logan, Utah
open path infrared CO_2/H_2O gas analyzer	model Li-7500	LI-COR, Inc., Lincoln, Nebraska
krypton hygrometer	model KH2O	Campbell Scientific, Inc
net radiometer	model CRN-1	Kipp and Zonen, Delft, The Netherlands
temperature and relative humidity sensor	model HMP45C	Campbell Scientific, Inc.
tipping bucket rain gauge	model TE525WS	Campbell Scientific, Inc.
time domain reflectometer (TDR)	model CS615	Campbell Scientific, Inc.

soil heat flux plates	model HFT3	Campbell Scientific, Inc.
soil thermocouples	5TC-GG series	Omega Engineering, Inc., Stamford, CT
infrared thermometers	model IRTS-S	Apogee Instruments, Inc., Logan, UT
data logger	model 23X	Campbell Scientific, Inc.

Post-processing of the data involved a two-angle coordinate rotation of the wind velocity components in order to align the coordinates with the mean wind directional components (McMillan, 1988). This technique was used to adjust for sloping terrain or a non-level sonic anemometer. The maximum correction needed for any of the four sites was 4°. Also, corrections were made for density changes resulting from fluctuations in heat and water vapor (Webb et al., 1980). In accordance with recent micrometeorological convention, fluxes toward the surface are designated as negative, while fluxes toward the atmosphere are positive.

Additional Sources of Information

Detailed photographs (.jpg) that complement the experimental descriptions for this data set are available on the S2K Photo Gallery pages.

Additional related data sets collected during the Kalahari Transect Wet Season Field Campaign are archived by ORNL DAAC. A list of these data sets is available at: http://www.daac.ornl.gov/S2K/safari.html.

References

Bégué, A., J. L. Roujean, N. P. Hanan, S. D. Prince, M. Thawley, A. Huete, and D. Tanre. 1996. Shortwave radiation budget of Sahelian vegetation. 1. Techniques of measurements and results during HAPEX-Sahel. Agricultural and Forest Meteorology, 79: 79-96.

McMillen, R. T. 1988. An eddy correlation technique with extended applicability to non-simple terrain. Boundary-Layer Meteorology, 43: 231-245.

Pinheiro A. and J. Privette. 2004. SAFARI 2000 Soil Properties, Moisture, and

Temp, Skukuza and Mongu, 1999 to 2001. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.

Privette, J. L., R. B. Myneni, Y. Knyazikhin, M. Mukufute, G. Roberts, Y. Tian, Y. Wang, and S. G. Leblanc. 2002. Early spatial and temporal validation of MODIS LAI product in the Southern Africa Kalahari. Remote Sensing of Environment, 83(1-2): 232-243.

Scanlon, T. M. and J. D. Albertson. 2004. Canopy scale measurements of CO_2 and water vapor exchange along a precipitation gradient in southern Africa. Global Change Biology, 10(3): 329-341.

Scholes, R. J., P. R. Dowty, K. Caylor, D. A. B. Parsons, and H. H. Shugart. 2002. Trends in savanna structure and composition along an aridity gradient in the Kalahari. Journal of Vegetation Science, 13(3): 419-428.

Schuepp, P. H., M. Y. Leclerc, J. I. MacPherson, and R. L. Desjardins. 1990. Footprint prediction of scalar fluxes from analytical solutions of the diffusion equation. Boundary-Layer Meteorology, 50: 355-373.

Webb, E. K., G. Pearman, and R. Leuning. 1980. Correction of flux measurements for density effects due to heat and water vapor transfer, 1980. Quarterly Journal of the Royal Meteorological Society, 106: 85-100.

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