Micrometeorological conditions and surface mass and energy fluxes on Lewis Glacier, Mt Kenya in relation to other tropical glaciers

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SUMMARY

- Strong diurnal cycle of convective cloud development - in contrast to Ruwenzori (Kilimanjaro) where overcast (clear) sky conditions prevail
- Compared to clear sky conditions, cloud cover reduces the net radiation balance and the associated higher rate of snow accumulation limits the rate of mass loss
- Surface mass balance influenced by solid precipitation and air temperature with radiation providing the greatest net source of energy to the surface
- Lower sublimation rate compared to other tropical glaciers and high year round melt rate (melt at the glacier surface almost daily)

INTRODUCTION & OVERVIEW

Objectives

- What climate signals are reflected in changes of East African glaciers?
- How do they relate to climate proxies offered by other tropical glaciers?

Methods

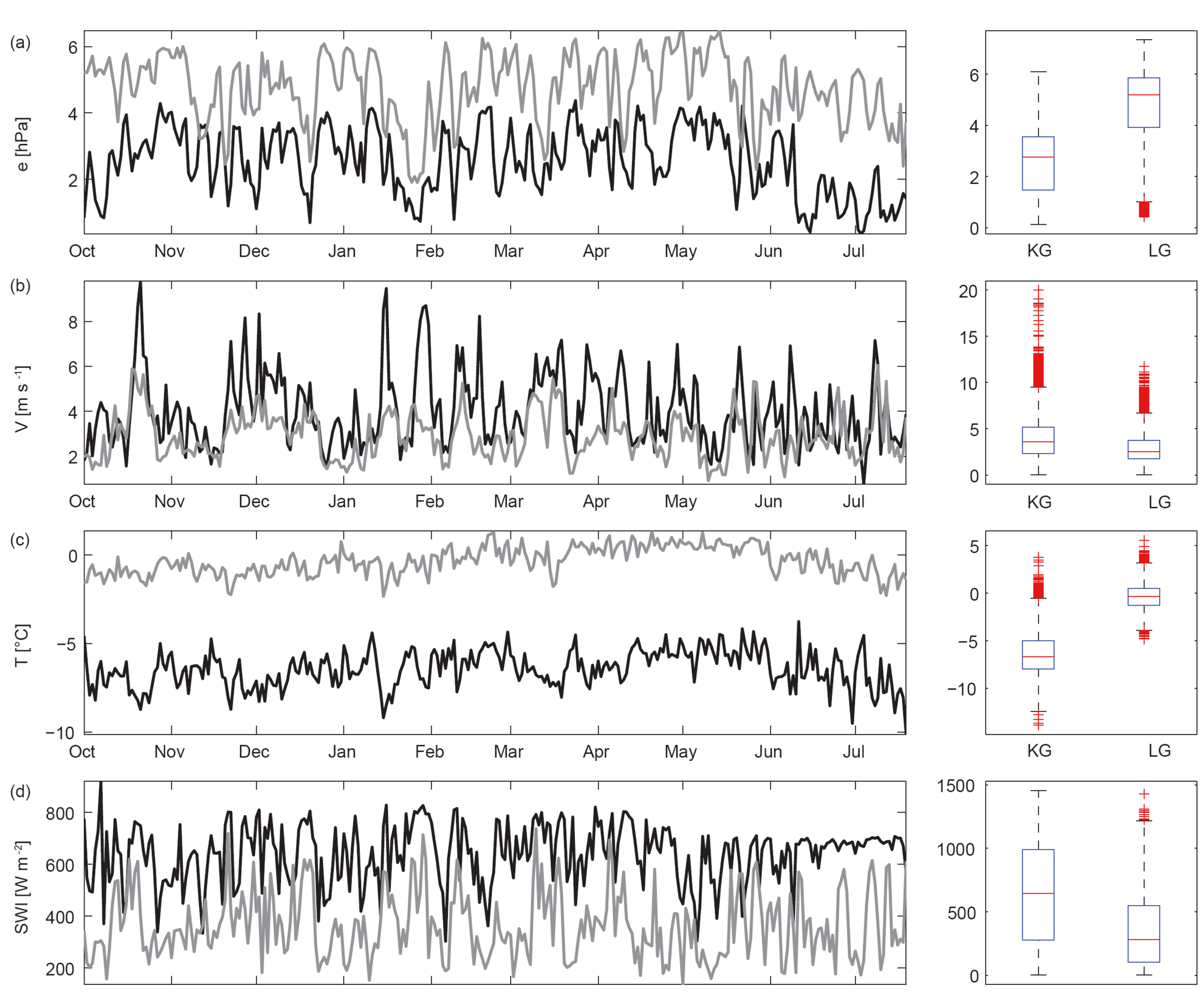
- 2.5 years of meteorological measurements on the surface of Lewis Glacier (October 2009 – February 2012) as input for a
- Process-based surface mass and energy balance model (Mölg et al., 2008) using
- Monte Carlo optimization to determine additional input parameters

Right: Comparison of the AWS locations used in this study: **LG**: Lewis Glacier (Mt Kenya); **EG**: Elena Glacier (Ruwenzori); **KG**: Kersten Glacier (Kilimanjaro); **AG**: Antizana Glacier (Ecuador); **ARG**: Artesonraju Glacier (Peru); **ZG**: Zongo Glacier (Bolivia)

	East African sites			South American sites		
	LG	EG	KG	AG	ARG	ZG
source	this study	Lentini et al. (2011)	Mölg et al. (2009a)	Favier et al. (2004b)	Juen (2006)	Favier et al. (2004a)
m a.s.l.	4828	4750	5873	4890	4850	5050
coordinates	0°09′ S 37°18′ E	0°22′ N 29°52′ E	3°04′ S 37°21′ E	0°28′ 78°09′ W	8°57′ S 77.38′ W	16°15′ S 68°10′ W
location	upper glacier inner tropics	off glacier inner tropics	upper glacier inner tropics	lower glacier inner tropics	lower glacier outer tropics	lower glacier outer tropics
sky view	88 %	–	98 %	95 %		94 %
date range [mm/yy]	09/09–07/10 09/10–02/12 36 days missing	10/06–08/07 07/08–06/09 8 % data missing	02/05–01/08 no data missing	03/02–03/03 16 days missing	04/04–04/05	08/99–08/00
T [°C]	−0.9 (0.8)	−0.35 (0.8)	−6.8 (1.1)	0.3 (0.7)	0.7 (0.8)	−0.8 (1.4)
T ice [°C]	−2.9 (1.6)	–	−8.9 (2.1)	−1.4 (0.7)		−3.1 (2.1)
RH [%]	75 (19)	90 (9)	56 (26)	81 (11)		71 (21)
q [$g\,kg^{-1}$]	4.7 (1.3)	–	2.6 (1.2)	5.5 (0.7)	4.8 (5.1)	4.7 (1.5)
V [$m\,s^{-1}$]	2.8 (1.0)	3.6 (2.3)	4.8 (2.5)	4.8 (3.5)	3.2 (2.8)	2.7 (1.2)
SWI [$W\,m^{-2}$]	191 (65)	121 (49)	339 (58)	239 (68)	230 (64)	209 (61)
LWI [$W\,m^{-2}$]	255 (33)	–	179 (44)	272 (29)	281 (34)	258 (45)
albedo	0.56 (0.17)	–	0.56 (0.13)	0.49 (0.18)	0.54 (0.18)	0.66 (0.18)
snow [mm w.e. d^{-1}]	2.94[a]	4.00[b]	1.36[a]	1.95		
P [hPa]	571 (0.9)	581 (0.7)	501 (0.7)	–		–

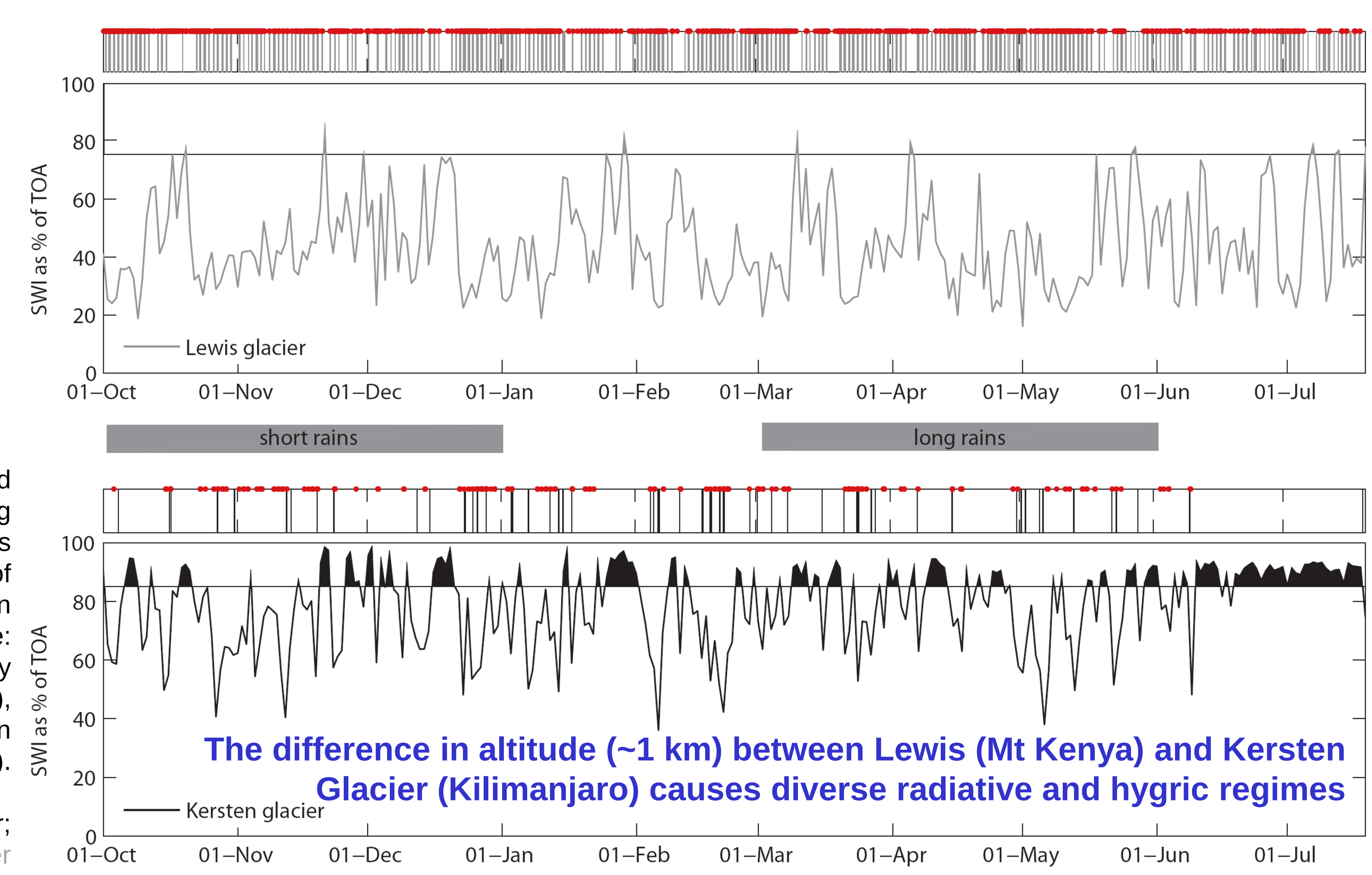
[a] Computed from daily snow depth accumulation multiplied by the 90th percentile density of fresh snow from all available field measurements which was 420 $g\,kg^{-1}$ at LG and 255 $g\,kg^{-1}$ at KG. [b] Is not solid precipitation accumulation but total precipitation in mm w.e.

METEOROLOGY



Left: Comparison of daily mean values of **e** (vapor pressure), **V** (wind speed), **T** (air temperature) and **SWI** (global radiation over daylight hours).

Black: Kersten Glacier; **Grey**: Lewis Glacier

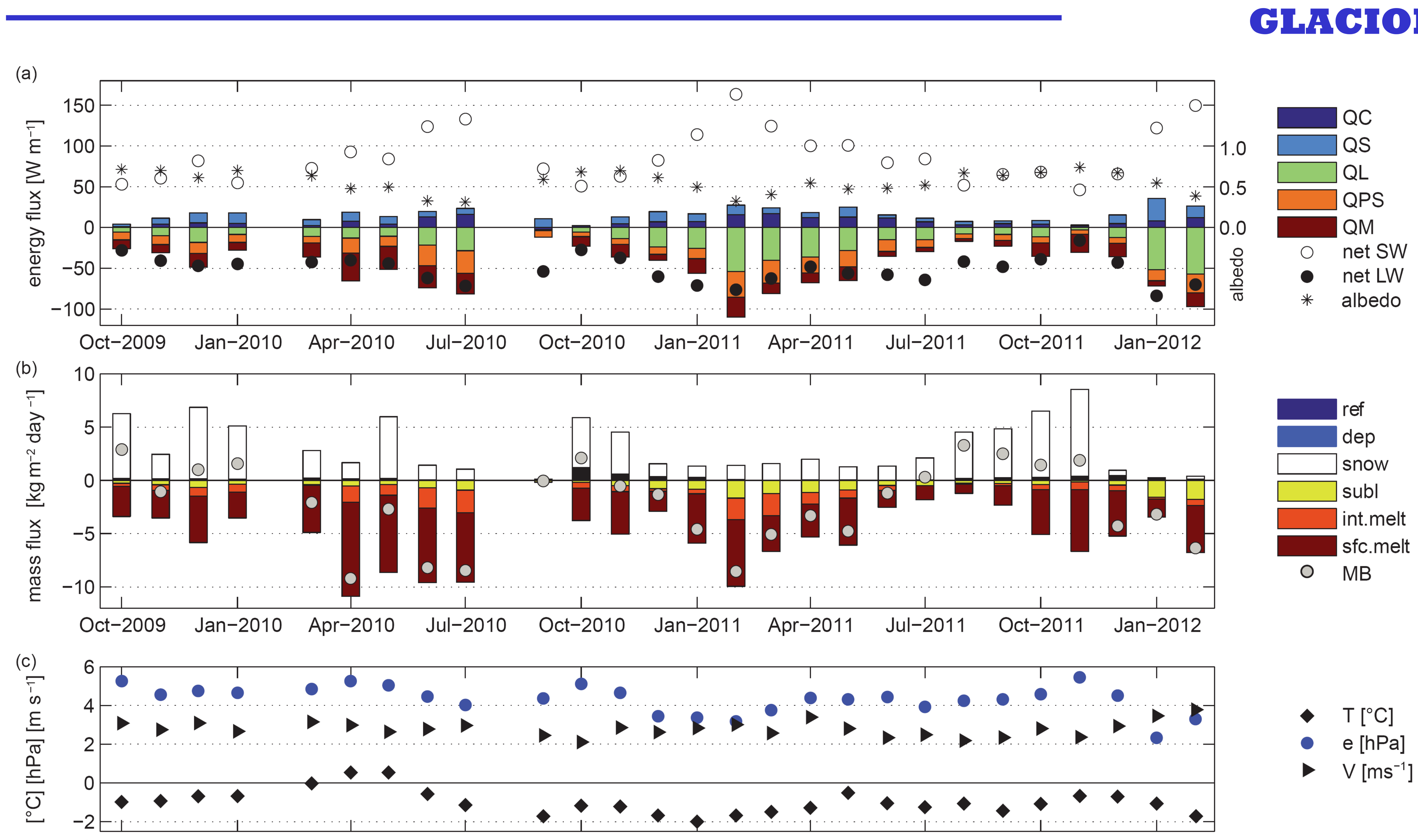


Right: Global radiation and cloudiness: Daily incoming shortwave (**SWI**) as percentage of top of atmosphere radiation (**TOA**). Panels above: hours of overcast sky conditions (vert. bars), hours of condensation conditions (red dots).

Black: Kersten Glacier; **Grey**: Lewis Glacier

The difference in altitude (~1 km) between Lewis (Mt Kenya) and Kersten Glacier (Kilimanjaro) causes diverse radiative and hygric regimes

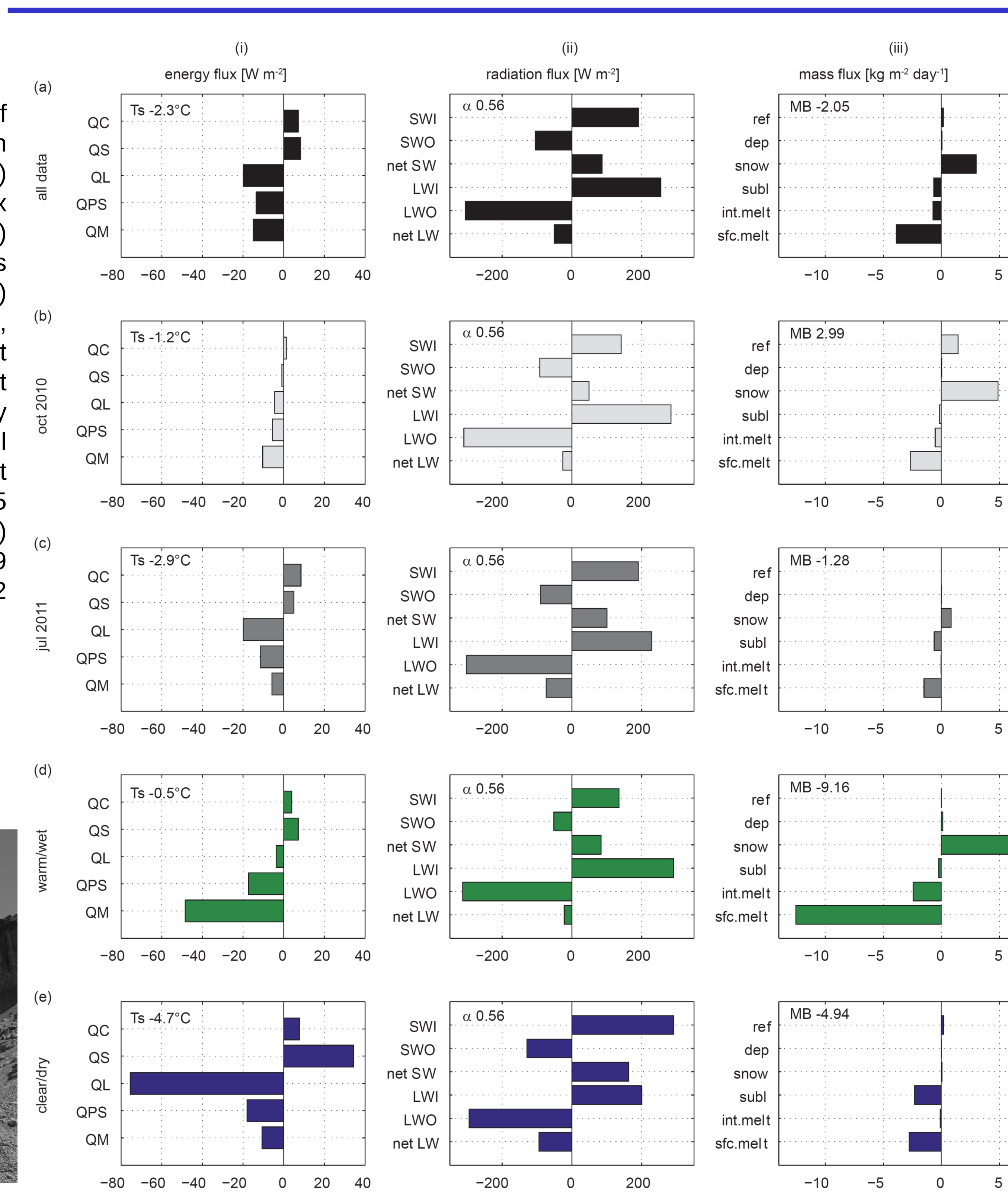
GLACIOLOGY



Above: (a) Monthly mean energy flux density of net shortwave radiation (**net SW**), net longwave radiation (**net LW**), conductive energy flux (**QC**), turbulent sensible energy (**QS**), turbulent latent energy (**QL**), penetrating shortwave radiation (**QPS**), energy for melting (**QM**) and surface albedo at Lewis Glacier **(b)** Monthly mean mass flux rate of refreezing (**ref**), surface deposition (**dep**), solid precipitation (**snow**), sublimation (**subl**) internal melt (**int.melt**), surface melt (**sfc.melt**) and net mass balance rates (**MB**). **(c)** Monthly means of air temperature (**T** [C]), vapor pressure (**e**[hPa]) and wind speed (**V** [m s⁻¹]).

Mass balance is dominated by radiative fluxes and modulated by turbulent fluxes in relation to air temperature, hygric conditions and surface albedo.

Right: Summary of (**columns**) **(i)** mean energy flux density, **(ii)** radiation flux components and **(iii)** mass fluxes at Lewis Glacier; (**rows**) **(a)** whole modeled period, **(b)** standard wet conditions (1-20 Oct 2010), **(c)** standard dry conditions (1-20 Jul 2011), **(d)** warm/wet extreme (26 Apr - 15 May 2010) and **(e)** clear/dry extreme (19 Jan – 7 Feb 2012)



References:

Mölg, T., N. J. Cullen, D. R. Hardy, G. Kaser, and L. Klok (2008), Mass balance of a slope glacier on Kilimanjaro and its sensitivity to climate, *International Journal of Climatology*, *28*, 881–892, doi:10.1002/joc.1589.

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