Identifying climatic drivers of glacier mass balance variability of Lewis Glacier, Mt Kenya

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BACKGROUND Low latitude glaciers can provide evidence of conditions in the tropical mid-troposphere, and how they have changed over recent decades.

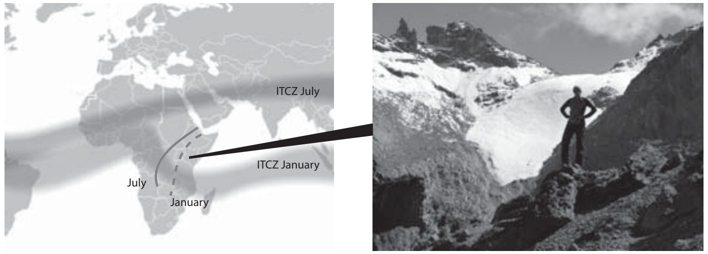


FIG 1: Location of Lewis Glacier (00°09'S; 37°30'E) and key tropical convergence zones (image from wikigraphics). On the right is the glacier as it was after a snowfall in 2010.

The regional climate is characterized by two rainy seasons: the 'long rains' (MAM) and 'short rains' (OND). East African precipitation has been related to ENSO[1], the Indian Ocean Zonal Mode[2] (IOZM) and the Madden-Julian Oscillation[3] (MJO).

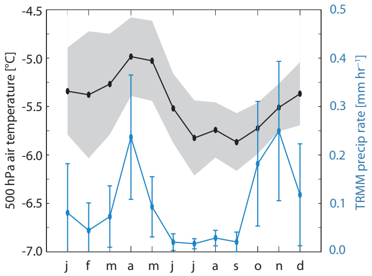
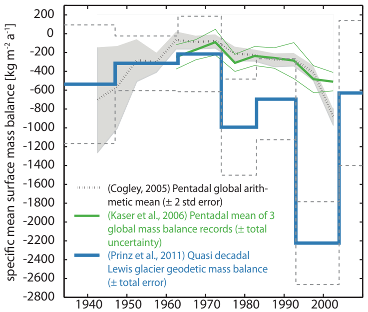


FIG 2: At Mt Kenya, April/May emerges as a thermal optimum in 500hPa ERA-interim air temperatures, while July-October are the coldest months. TRMM data indicates that the long rains are expressed primarily in April, coinciding with the thermal optimum, while the short rains span October-December. June - September are months with consistently low precipitation rates, while January and February precipitation is higher and more variable.

What climatic conditions control mass changes at Lewis Glacier?
What climate conditions could have given rise to former glacier extents?

HISTORICAL RECORDS OF LEWIS GLACIER IN THE CONTEXT OF GLOBAL MASS BALANCE Evidence of extensive former Pleistocene and Early Holocene glaciation is lacking tight chronology, but historical records show that Lewis glacier has undergone continuous retreat since the late 19th century.

FIG 3: Geodetic specific mass balance of Lewis Glacier determined from field maps at ~10 year intervals since 1934 (Prinz et al., 2011), indicate mass balance was broadly in-line with global estimates up until 1974, when a period of much more rapid mass loss ensued until 2004.



Lewis glacier in 2010: total ice volume $=1.90 \pm 0.30 \times 10^6\ m^3$, ice area $= 0.105 \pm 0.001 \times 10^6\ m^2$, mean (max) thickness $=18 \pm 3$ m (45 ± 3 m).

REFERENCES:
(1) Indije et al., 2000, Int. J. Climate, 20;
(2) Mölg et al., 2006, GRL, 33 and Hastenrath et al., 2010, J. Climate;
(3) Pohl and Camberlin, 2006, Q. J. R. Meteorol. Soc., 132;
(4) Prinz et al., 2011, GRL, 38
(5) Hastenrath, 2005

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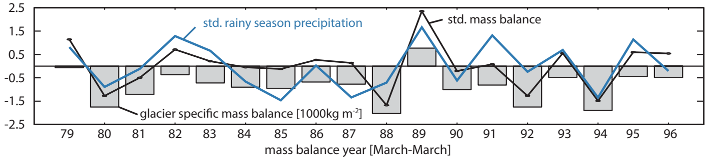
RELATIONSHIP OF HISTORICAL ANNUAL MASS BALANCE WITH PRECIPITATION RECORDS 18 years of directly measured annual mass balance (AMB) are available from the Lewis glacier: 03/1978 - 02/1996[5]. 8 stakes were measured at ~monthly intervals allowing a seasonal surface height change (SSHC) record to be derived. Accumulating rainguages at 4800, 4400 and 3050m show that precipitation amounts decrease with elevation, and seasonal precipitation totals (SP) are comparable during both rainy seasons.



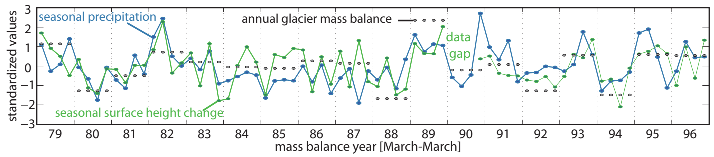
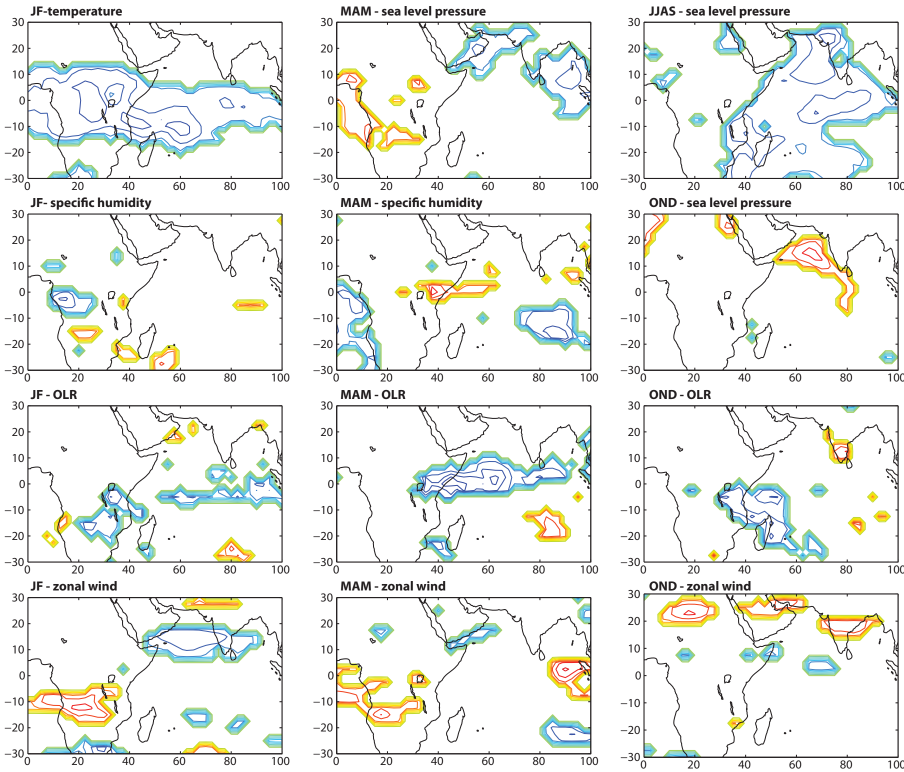


FIG 4: Interannual variability of AMB measurements is strongly related to total rainy season (MAM + OND) precipitation at 4800m (r 0.69), suggesting that AMB is most strongly governed by precipitation. Positive AMB occurred only in the 1989 mass balance year, and the most negative AMBs occurred in 1980, 1988, 1992 and 1994.

FIG 5: Seasonal (MAM, JJAS, OND and JF) values of SSHC and SP correspond well for much of the record (r 0.48), but are sometimes anti-correlated. Positive (negative) AMB anomalies occur when 3/4 seasons experience positive (negative) anomalies in SP and SSHC, suggesting that no single season drives AMB variability.

RELATIONSHIP OF GLACIOLOGICAL RECORDS WITH CLIMATE INDICES AMB is correlated significantly with annual ENSO MEI (r -0.34). On seasonal timescales SP is not correlated with ENSO MEI, but SSHC is in MAM (r -0.43) and in JF (r -0.47), indicating that surface change during these seasons may be influenced by higher ablation rates associated with the warmer tropical atmosphere experienced during periods with positive ENSO index. No significant relationships were found between SSHC and the IODM index. SSHC is related to the MJO index during the dry seasons [JJAS (r -0.56) and JF (r -0.22)], indicating that active phases of the MJO during the dry seasons might bring enhanced accumulation or reduced ablation to the glacier. A sustained negative excursion in the MJO index is also evident during the positive mass balance year of 1989.

CORRELATION WITH GRIDDED CLIMATE DATASETS Correlations were performed between the field records and (i) ERA reanalysis data (at 600 and 850 hPa levels) ; (ii) NOAA outgoing longwave radiation (OLR) and (iii) HadSST sea surface temperature.



On annual timescales, AMB is positively correlated with moisture parameters at the 600hPa level in the local region of Mt Kenya, and negatively correlated with surface solar radiation receipts and OLR extending in a belt from 30-80°E along the Equator --> on annual timescales a moister and cloudier atmosphere benefits the glacier. On seasonal timescales, SSHC in the wet seasons, show similar relationships to the annual timescale, with the relationships in MAM > those in OND. No significant correlations exist during the JJAS season while JF shows a negative relationships with air temperature as well as positive relationship with humidity.

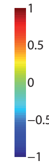


FIG 5: Example spatial correlations (r) between Lewis Glacier seasonal surface height change (SSHC) anomalies and seasonal gridded climate anomalies.

JF +ve SSHC: lower temperature in tropical belt; lower specific humidity over equatorial W. Africa; negative OLR over E. Africa 0-20°S and positive zonal wind anomaly across southern Africa continent.

MAM +ve SSHC: higher sea level pressure off equatorial W. Africa associated with anomalous zonal wind over same region; narrow belt of positive equatorial specific humidity anomalies 35.60°E associated with a belt of more negative OLR extending to 80°E.

JJAS +ve SSHC: low pressure over whole Indian Ocean basin.

OND +ve SSHC: high sea level pressure in Arabian Sea; negative OLR anomaly over Tanzania-Madagascar, extending to 60°E; zonal wind anomaly at 20°N.