9D.7 THE QBO'S INFLUENCE ON LIGHTNING PRODUCTION IN THE TROPICS

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1. INTRODUCTION

The Quasi-Biennial Oscillation (QBO) is a 24-30 month oscillation of the equatorial zonal winds in the lower stratosphere. During this period zonally symmetric easterly (east phase) and westerly (west phase) wind regimes will regularly alternate (Lindzen & Holton, 1968). Closely associated warm and cold stratospheric temperature anomalies accompany the different wind regimes as they propagate lower into the atmosphere (Gray et al., 1992). The QBO has been postulated to influence deep convection via changes in tropopause height and upper tropospheric to lower-stratospheric wind shear (Collimore et al., 2003). Because lightning is a response to thermodynamic and dynamic forcing, Tropical Rainfall Measuring Mission (TRMM) Lightning Imaging Sensor (LIS) data can be used as a proxy for deep convection (Christian et al., 1999).

As the easterly and westerly wind shear regimes propagate downward, an anomalous meridional circulation is induced (Collimore et al., 2003). Due to contrasting thermal regimes, hydrostatic effects in the lower and upper stratosphere may favor equatorial convection during the east phase (Gray et al., 1992). More specifically, the east (west) phase induces anomalous motion that leads to a cooler, higher (warmer, lower) tropopause near the equator (Fig. 1). Temperature anomalies in areas 10-20° off the equator are 180° out of phase with those near the equator. Therefore, strong east phase cooling near the equator is accompanied by a weak warming in off-equator regions. By this notion, it is anticipated that lightning flash densities near the equator will increase during the east phase and decrease during the west phase.

Flash densities may also be affected by the QBO's modulation of upper-tropospheric to lower-stratospheric wind shear (i.e., between 50 and 200 hPa). The east (west) phase of the QBO induces weak (strong) vertical shear in and near equatorial regions. The reverse scenario is expected in off-equator regions. Upper-tropospheric zonal winds associated with the QBO show some geographical variation near the equator (Collimore et al.; 2003, Hamilton et al., 2004). Therefore, the increase/decrease of flash densities due to shear may not only depend on the phase of the QBO but also on the location. Weak shear will allow convection to extend further into the atmosphere while strong shear will shear cloud tops off.

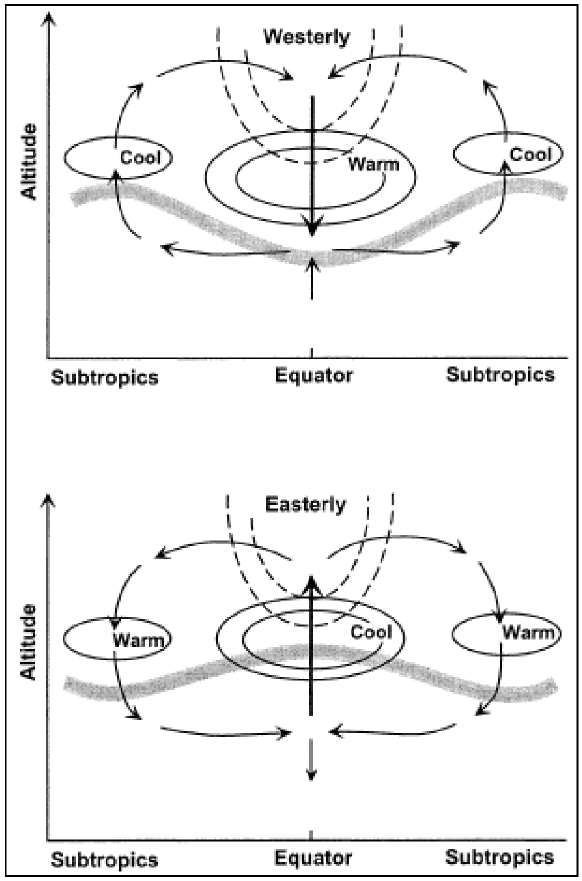

FIG. 1. Schematic representation of QBO modulation through tropopause height during the west (top) and east (bottom) phase. The thick gray line represents the tropopause (Adapted from Collimore et al., 2003).

This study focuses on examining the relationship between the QBO and flash densities through modulation of tropopause height and upper-tropospheric to lower-stratospheric shear for four regions: Africa, India, Indonesia/Australia, and South America. It is hypothesized that lightning flash densities will increase (decrease) during the east (west) phase near the equator and decrease (increase) during the east (west) phase in off-equator regions with different contributions from tropopause height and wind shear variations.

2. DATA

TRMM Lightning Imaging Sensor (LIS) data

A monthly climatology of eight years (1998-2005)

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of lightning flash densities was obtained from the Global Hydrology Resource Center (http://thunder.msfc.nasa.gov/data). The Low Resolution Monthly Time Series (LRMTS) is binned into a 2.5° x 2.5° grid. Flash densities are composited into west-east total and seasonal anomalous monthly mean difference maps. The annual cycle was removed by subtracting each calendar month mean from their respective raw monthly value.

NCEP reanalysis

Monthly temperature and zonal wind data were taken from the National Centers for Environmental Prediction-Nation Center for Atmospheric Sciences (NCEP-NCAR) reanalysis. NCEP data were interpolated and remapped into 2.5° x 2.5° grids to match TRMM LIS data binning. Tropopause temperatures and zonal winds are composited into west-east total and seasonal anomalous monthly mean difference plots. Most of the interactions linking the QBO to deep convection occur in and near the tropopause. Therefore, the phases of the QBO are determined by a 50-70hPa shear index (Huesmann & Hitchman, 2001; Collimore et al, 2003). West phase months are defined as months with 50-70hPa shear values ≥ 1.5 m s^{-1}. Months in the east phase have 50-70hPa shear values ≤ -1.5 m s^{-1}.

3. RESULTS

Modulation through Tropopause Height

The relationship between flash densities and tropopause temperature varies for each region and season. However, QBO modulation through tropopause height is best represented during the MAM season. Maps of W-E flash densities, W-E tropopause temperatures, and correlation coefficients between anomalous flash densities and anomalous tropopause temperatures for MAM are given in Fig. 2.

Africa Negative correlations (i.e., an increase in flash densities with higher/colder tropopause temperatures during the east phase) are greater and more prevalent in this region except over the Saharan Desert and Congo Basin. Correlations of -0.6 indicate the relationship between lightning and height is moderate-to-strong.

India Flash densities are higher over the northern subcontinent during the west phase and higher over the southern subcontinent during the east phase. Small correlations indicate that these signals are weakly related to the QBO tropopause temperature changes.

Indonesia/Australia W-E flash densities and W-E tropopause temperatures for Indonesia and Australia are weak. Correlation coefficients reach a minimum of -0.3, while maximum correlation coefficients are 0.1. Thus, QBO modulation plays a small role in this area during MAM.

South America Comparison of flash density and tropopause temperature anomaly patterns and values illustrate the tendency for flash densities to increase when the tropopause is higher during the east phase. Correlations in South America reach values of -0.6 to -0.7, suggesting the connection between tropopause height and lightning is moderate-to-strong during the QBO.

Modulation through Shear

QBO modulation through shear is strongest during DJF and JJA. Maps of W-E flash densities, W-E 50-200hPa absolute shear, and correlation coefficients between anomalous flash densities and anomalous 50-200hPa absolute shear for DJF are given in Fig. 3.

Africa W-E LIS anomaly maps show strong flash density anomalies in the east and west phase. Small correlations in the equatorial region suggest a weak connection to the QBO shear mechanism. Correlations of -0.6 off the coasts of Angola and Namibia indicate a moderate relationship between the QBO and flash densities during DJF.

India There is essentially no QBO lightning signal over the Indian subcontinent during DJF mostly likely because there is a lack of deep convection in the region during boreal winter.

Indonesia/Australia Correlations over Indonesia reach values around -0.6 and -0.7 indicating that flash densities tend to increase when upper-tropospheric to lower-stratospheric shear is weak during the east phase. However, positive correlations over Australia and the larger islands in the Maritime continent indicate that more lightning occurs in the west phase when shear is stronger. Other mechanisms are likely responsible for the increase in flash density changes in these regions.

South America Over the Amazon basin, positive correlations show an increase in flash densities during the west phase when vertical shear is strong. Flash densities increase in the east phase when shear is weak in the southern and eastern portion of Brazil. Negative correlations reaching values of -0.7 to -0.8 suggest that the QBO modulation through upper-tropospheric to lower-stratospheric shear strongly affects the flash densities in the southern and eastern portion of South America.

4. SUMMARY AND FUTURE WORK

W-E differences of LIS, temperature, and absolute shear anomalies and corresponding correlations show that the relationship between the QBO and lightning varies for each season and region. QBO modulation through tropopause height is

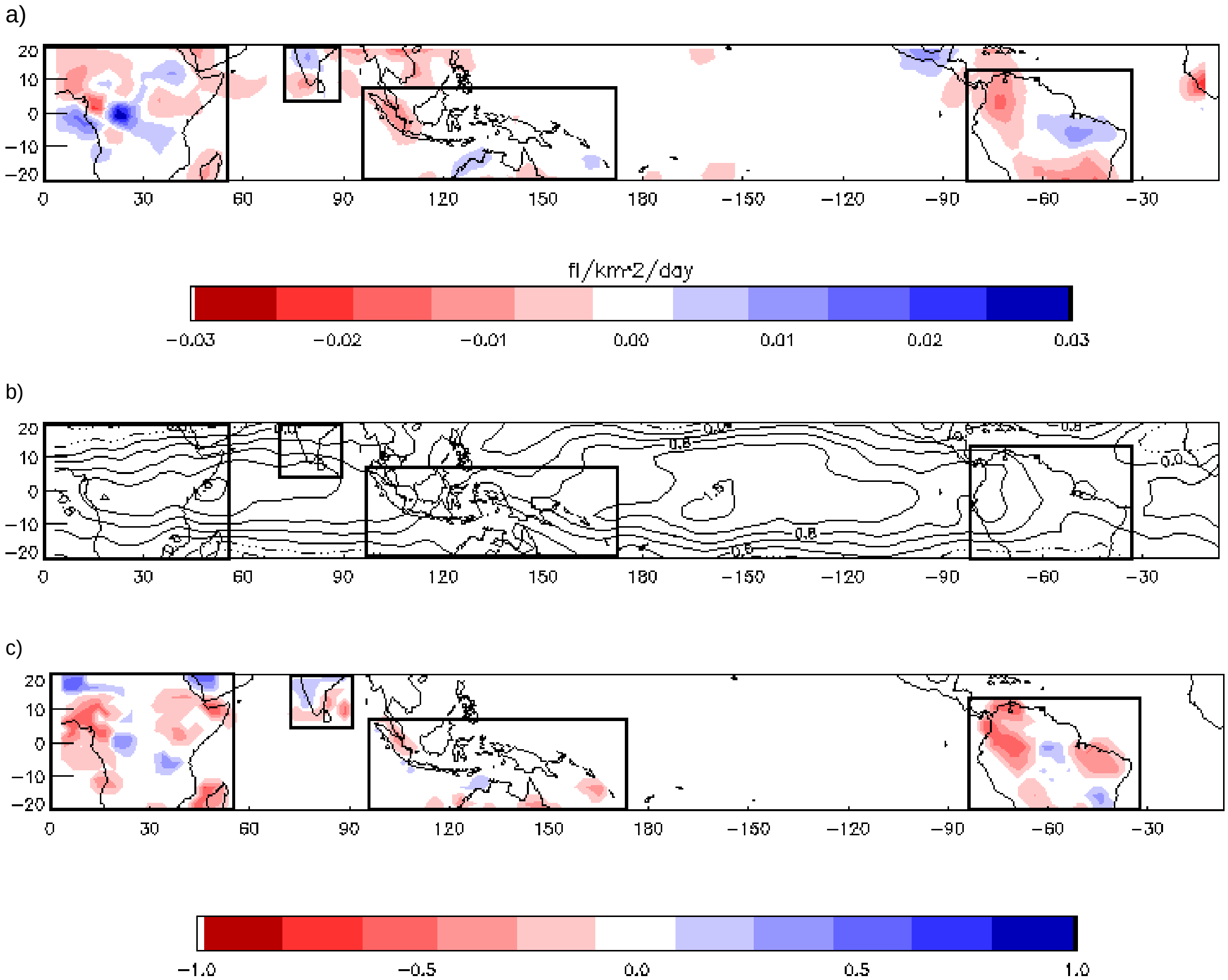

FIG. 2. Plots representing QBO modulation through height for MAM: a) Monthly mean W-E LIS anomalies. Units are fl km^{-2} day^{-1}., b) W-E tropopause temperature anomalies. Units are °C., c) Correlation coefficients between anomalous LIS monthly means and anomalous tropopause temperature.

moderate throughout all seasons. QBO modulation through upper-tropospheric to lower-stratospheric shear is moderate during MAM and SON and strongest during DJF and JJA.

As the MAM plots illustrate, the tropopause is higher/cooler during the east phase near the equator and lower/warmer during the west phase. The effect of QBO tropopause temperature modulation on lightning varies from region to region as is seen in Fig 2c. Both Africa and South America experience increased flash densities during the east phase. However, India and the Indonesia/Australia region experience less change in flash densities due to the QBO in MAM.

In general, upper-tropospheric to lower-stratospheric wind shear is weaker (stronger) during the east (west) phase over the near-equatorial continental regions. Correlations indicate a moderate-to-strong relationship between flash densities and vertical shear in Africa, Indonesia/Australia, and South America. However, positive correlations show that the QBO hypothesis is not valid for all regions.

Future work will investigate the QBO relationship with TRMM Precipitation Radar (PR) data including echo top height, rainfall rates, vertical reflectivity structure, and convective and stratiform characteristics.

5. ACKNOWLEDGEMENTS

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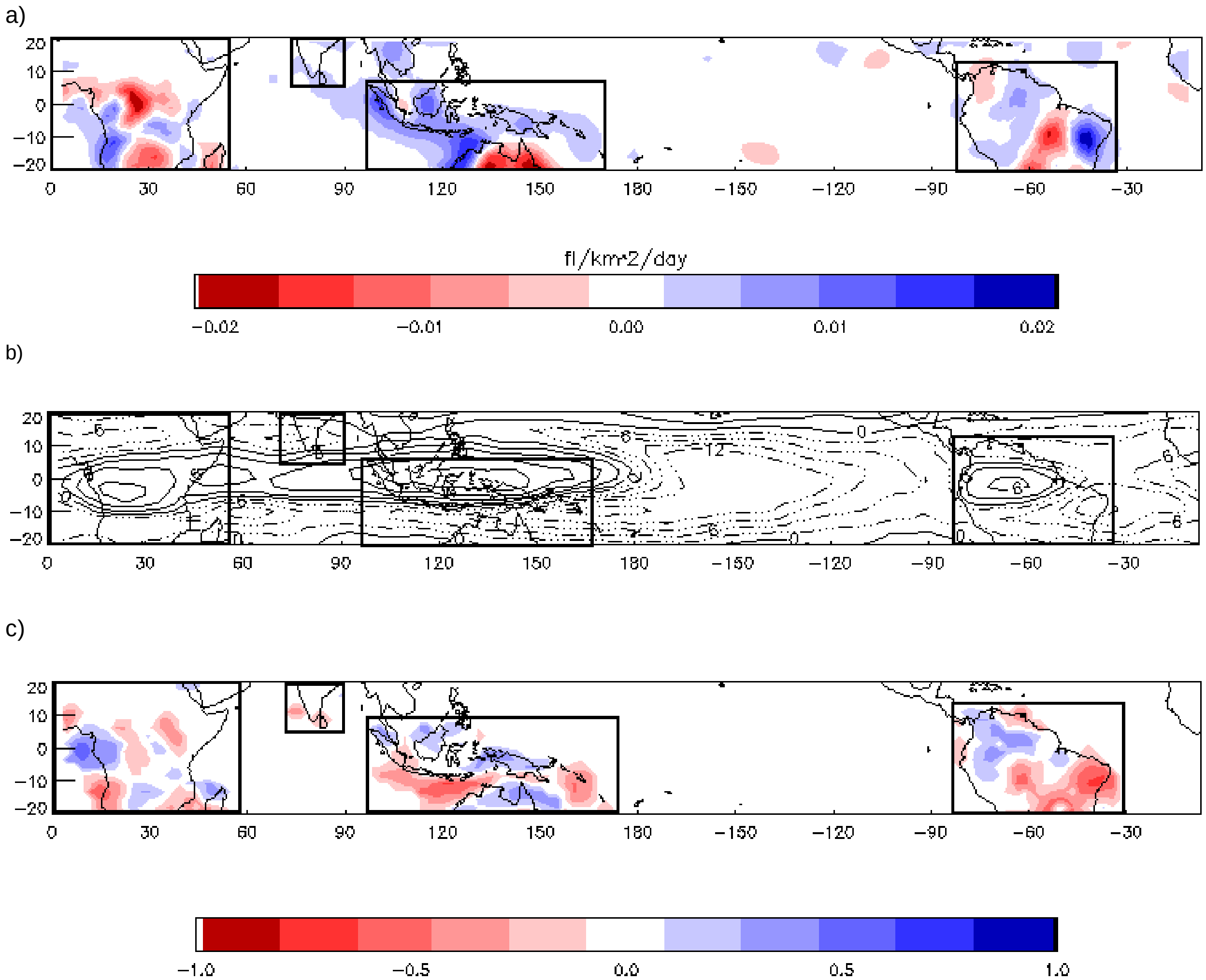

FIG. 3. Plots representing QBO modulation through shear for DJF: a) Monthly mean W-E LIS anomalies. Units are fl km^{-2} day^{-1}., b) W-E absolute 50-200hPa shear anomalies. Units are m s^{-1}., c) Correlation coefficients between anomalous LIS monthly means and anomalous 50-200hPa shear.

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