4.3 METEOROLOGICAL ORIGIN OF Q-BURSTS AND SPRITES OVER WEST AFRICA

Earle Williams*
Massachusetts Institute of Technology
Y. Hobara
University of Sheffield, UK
R. Boldi
University of Alabama
W. Lyons, T. Nelson
FMA Research Inc.
B. Russell
University of Michigan
V. Mushtak
Massachusetts Institute of Technology
G. Satori, J. Bor
GGRI, Sopron, Hungary
S. Cummer
Duke University
C. Price, E. Greenberg
Tel Aviv University, Israel
Y. Takahashi
Tohuku University, Japan
R. Holzworth
University of Washington

1. INTRODUCTION

Among the three major tropical land regions, Africa stands out prominently as a source for lightning (Christian et al, 2003; Williams and Sátori, 2004). This preferred status was identified in early analysis of the global electrical circuit (Whipple, 1929). Possible meteorological reasons for this African dominance have been considered (Williams and Sátori, 2004; Williams; 2005, 2008). The present study is concerned again with African lightning, but with mesoscale events—flashes with extraordinary energy and vertical charge moment that single-handedly excite the Earth's Schumann resonances, and simultaneously initiate sprites in the mesosphere (Williams, 2001). The meteorological origins of such events are of special interest here, and have been investigated in a recent 2006 field experiment called African Monsoon and Multidisciplinary Analysis (AMMA).

2. METHODOLOGY

The MIT Doppler radar was installed in Niamey, Niger in June 2006 in support of AMMA. This radar was operated round-the-clock for three months (July, August and September) with full-volume-scan observations at 10-minute intervals. Local lightning events were documented with an electric field mill and slow antenna, with digital recordings time-stamped with input from a GPS receiver. Lightning events seen from great distances were documented with ELF receivers (Huang et al, 1999; Williams et al, 2006) in Hungary (Nagycenk Observatory), Israel (Mitzpe Ramon), Japan (Moshiri Observatory) and the United States (West Greenwich, Rhode Island and Duke University, North Carolina). The integration of these various measurements has served to provide context for the energetic lightning flashes in West Africa.

3. THE GLOBAL PERSPECTIVE

Africa's predominance in lightning observations made from satellites is now well established (Christian et al, 2003; Williams and Sátori, 2004). More recently, ground–based electromagnetic measurements in the ELF region (Schumann resonances) have been used to create global maps of 'mesoscale' lightning (Hobara et al, 2006). These results again show African dominance among tropical 'chimney' regions, with a notable surplus of positive over negative polarity. The contrast with the Amazon basin of Brazil is particularly noteworthy, and is consistent with the infrequence with which large and energetic 'spider'

*Corresponding author address: Earle R. Williams, MIT Parsons Laboratory, Cambridge, MA 02139; email: earlew@ll.mit.edu

lightning flashes were noted during the NASA TRMM LBA field program in Ji Parana, Rondonia, Brazil during 1999 (Williams et al, 2002).

The evidence via Schumann resonance observations for Africa prominence in mesoscale lightning flashes is also consistent with global maps from ISUAL satellite observations (A. Chen, personal communication, 2007) showing African dominance in sprite production.

4. THE CHIMNEY-SCALE PERSPECTIVE

Toward clarifying the differences in nature of lightning-producing convection in the Amazon and in West Africa, the radar movies from previous field experiments in the two regions have been compared. The Amazon is characterized by disorganized air mass convection, with initiation often near midday. The West African convection has a delayed diurnal cycle but shows a great prevalence for mesoscale organization and large squall lines. This mesoscale organization serves to accumulate large reservoirs of positive electricity in stratiform regions which appear to be favorable to the superlative lightning flashes of primary interest in this study. The probable reason for the contrast in mode of convection between Amazon and West Africa is baroclinicity—the presence of large-scale horizontal temperature gradients. The latitudinal temperature gradient in the Amazon in modest and the background for convection tends to be barotropic. West Africa, in contrast, is strongly baroclinic by virtue of the juxtaposition of the hot Sahara Desert and the cooler high-rainfall zone to its south.

Within the African continent, one can also contrast the baroclinicity of West Africa and the Congo basin straddling the equator. Whereas the Congo is less baroclinic that West Africa, it is decidedly more baroclinic than the Amazon region. Westward-moving squall lines in the Congo are initiated by outflows from convection in the more elevated terrain on the eastern edge of this large drainage basin, and serve to provide greater mesoscale organization than one finds in tropical South America. Lightning maps for Africa produced by single-station Schumann resonance methods show an abundance of positive ground flash activity in the Congo, but still less than in West Africa.

5. THE SQUALL LINE PERSPECTIVE

More than 25 squall line cases have been documented in Niamey, Niger during the 2006 wet season. The majority of these squall lines are westward propagation and many are components of African easterly waves.

As one relative measure of the size and extent of statiform charge reservoirs in these squall lines, the front-to-rear extents were measured with radar data. For minimum ambiguity and for purposes of eventual comparisons with the squall lines in other locales, the front-to-rear extents are defined as the maximum distance between the front edge and of the leading deep convection and the minimum detectable reflectivity at the rear end of the trailing stratiform region, at the altitude of the radar bright band (~4 km AGL). These maximum extents range from 140 km to over 300 km (with a mean extent of 230 km), and tend to be large in comparison with preliminary comparisons elsewhere (Houze et al, 1990; W. Lyons, T. Nelson, S. Rutledge and L. Carey, personal communication, 2008). The African extents are expected to be large for at least two reasons: (1) the durations of mesoscale events in Africa are long (and particularly in contrast with Amazon cases (Laurent and Machado, 2001) and (2) the boundary layer concentrations of CCN and ice nuclei in Africa are the largest among tropical continental 'chimneys'.

The large lightning-related changes in electrostatic field at the MIT radar site have been documented with the electric field mill and slow antenna for all squall line cases. Large field changes indicative of negative cloud-to-ground lightning are prevalent when the leading line is nearby, consistent with a large body of results in other locales. As the stratiform region moves over and the radar bright band reaches maturity, the large amplitude ground flashes with positive polarity are most evident. This finding is also consistent with findings in other locales (Boccippio et al, 1995; Lyons et al, 2003).

The times of the special local events have been distributed to operators of distant ELF/Schumann resonance receiving stations worldwide, where event arrivals are also time-tagged using GPS receivers. This procedure enables the identification of common events. In most cases, the polarity of the lightning flash can be determined, and in some cases the vertical charge moment of the flash (Huang et al, 1999; Hobara et al, 2006) can be estimated. Such comparisons for numerous events documented in this collection of squall lines shows increasingly that the principle origin for the resonance-ringing positive ground flashes is the trailing stratiform region with radar bright band. In cases for which

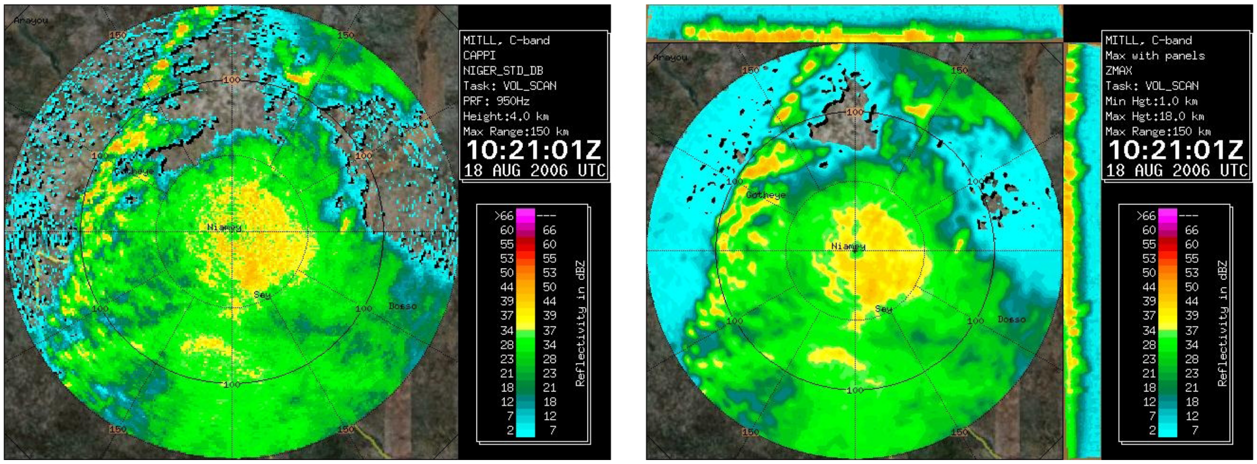

Figure 1 Radar CAPPI and ZMAX plots for the squall line on August 18, 2006. This represents the period at the radar when energetic positive ground flashes with spider lightning is present over the radar.

multiple receivers document the same local Niamey event, the great circle paths, identified by magnetic bearing measurements, can be traced back to the origin in the vicinity of the MIT radar site.

This consistently observed situation is illustrated for the August 18 squall line case in Figure 1. This figure shows a CAPPI (Constant Altitude Plan Position Indicator) of the entire squall line and trailing stratiform region. The leading deep convection lies to the west and the prominent radar bright band is roughly centered on the radar location at the origin. The measured front-to-rear extent is 275 km. Observations from the control tower at Niamey International Airport (across the airport runway from the MIT radar location) showed evidence for laterally extensive 'spider' lightning discharges with thunder durations exceeding 60 seconds. The remote Schumann resonance observations documented positive ground flashes with changes in vertical charge moment exceeding 500 C-km.

Radar, electrical and electromagnetic comparisons of a similar nature were carried out to explore the meteorological origins of lightning flashes with negative polarity that also serve to excite the Schumann resonances. Consistent with the findings for the positive flashes, mesoscale organization of convection is needed to produce these events. In the case of July 11, a sequence of large field-change negative flashes was observed from a convective region overhead with horizontal extent of order 100 km. This scale is an order of magnitude larger than that of ordinary thunderstorms, known to produce negative cloud-to-ground lightning but with vertical charge moments 5-10 times less than this event (-500 C-km).

6. CONCLUSIONS

The meteorological origins of lightning flashes conducive to single-handed ringing of the Earth's Schumann resonances have been traced to mesoscale convection in West Africa. The events with positive polarity have been shown to originate in the laterally extensive stratiform regions of westward-propagating squall lines, characterized by mature radar bright bands. The greater prevalence of such events in West Africa is attributed to baroclinicity which ultimately serves to organize positive charge reservoirs into laterally contiguous sheets of space charge.

7. ACKNOWLEDGEMENTS

We are indebted to C. Thorncroft for his persistence in obtaining a Doppler radar for Africa. T. Lebel, A. Diedhiou, F. Cazenave, S. Boubkraoui, M. Gosset and M. Abdoulaye provided guidance and assistance with the Niamey radar installation. Radar participants N. Nathou, L. Machado, T. Rickenbach, E. Freud, G. Lebel, F. Angeles, A. Ali, A. Mahamadou, Katiellou. A.Williams, and G. Williams helped maintain the electric field recordings during the field program. We thank T. Rickenbach for radar movies from the TRMM LBA experiment. The radar deployment and operation for AMMA were supported by Dr. Jared Entin at NASA Hydrology. Based on a French initiative, AMMA was built by an international scientific group and is currently funded by a large number of agencies, especially from France, UK, US and Africa. It has been the beneficiary of a major financial contribution from the European Community's Sixth Framework Research Programme.

8. REFERENCES

Boccippio, D.J., E. Williams, S.J. Heckman, W.A. Lyons, I. Baker and R. Boldi, 1995: Sprites, ELF transients and positive ground strokes, Science, 269, 1088-1091.

Christian, H.J., R.J. Blakeslee, D.J. Boccippio, W.L. Boeck, D.E. Buechler, K.T. Driscoll, S.J. Goodman, J.M. Hall, W.J. Koshak, D.M. Mach, and M.F. Stewart, 2003: Global frequency and distribution of lightning as observed from space by the Optical Transient Detector, J. Geophys. Res., 108, 4005, doi: 10.1029/2002JD002347.

Hobara, Y., M. Hayakawa, E. Williams, R. Boldi and E. Downes, 2006: Location and electrical properties of sprite-producing lightning from a single ELF site, in Sprites, Elves and Intense Lightning Discharges, Ed. M. Fullekrug, E.A. Mareev and M. J. Rycroft, NATO Science Series, II, Mathematics, Physics and Chemistry- Vol. 225, Springer.

Houze, R.A., Jr., B.F. Smull and P. Dodge, 1990: Mesoscale organization of springtime rainstorms in Oklahoma, Mon. Wea. Rev., 118, 613-654.

Huang, E., E. Williams, R. Boldi, S. Heckman, W. Lyons, M. Taylor, T. Nelson and C. Wong, 1999: Criteria for sprites and elves based on Schumann resonance observations, J. Geophys. Res., 104, 16943-16964.

Laurent, H. and L.A.T. Machado, 2001: Comparison of characteristics of convective systems observed in Amazonia and in Africa (in Portuguese), Second LBA Workshop, Belem, Brazil.

Lyons, W.A., T.E. Nelson, E.R. Williams, S.A. Cummer and M.A. Stanley, 2003: Characteristics of sprite-producing positive cloud-to-ground lightning during the 19 July 2000 STEPS mesoscale convective systems. Mon. Wea. Rev., 131, 2417-2427.

Whipple, F.J.W., 1929: On the association of the diurnal variation of electric potential gradient in fine weather with the distribution of thunderstorms over the globe, Quart. J. Roy. Met. Soc., 55, 1-17.

Williams, E.R., Sprites, elves and glow discharge tubes, Physics Today, November, 41-47, 2001.

Williams, E.R., 2005: Lightning and climate: A review, Atmospheric Research, 76, 272-287.

Williams, E.R., 2008: The global electrical circuit: A review, Atmospheric Research, (in review).

Williams, E.R., and Coauthors, 2002: Contrasting convective regimes over the Amazon: Implications for cloud electrification, J. Geophys. Res., LBA Special Issue, 107, D20, 8082, doi:10.1029/2001JD000380.

Williams, E.R. and G. Sátori, 2004: Lightning, thermodynamic and hydrological comparison of the two tropical continental chimneys, J. Atmos. Sol. Terr. Phys., 1213-1231.

Williams, E., R. Boldi, J. Bór, G. Sátori, G. Price, E. Greenberg, Y. Takahashi, K. Yamamoto, T. Chronis, E. Anagnostou, D. Smith, and L. Lopez, 2006: Lightning flashes conducive to the production and escape of gamma radiation to space, J. Geophys. Res.,111, D16209, doi:10.1029/2005JD006447.