AFRL-AFOSR-VA-TR-2016-0083

Low Latitude Aeronomy Study in Africa

Qian Wu
UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

02/09/2016
Final Report

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB1
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
08-02-2016

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
from 15-04-2013 to 14-04-2016

4. TITLE AND SUBTITLE
Low Latitude Aeronomy Study in Africa

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-13-1-0174

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Qian Wu

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR) 3150 CENTER GREEN DRIVE BOULDER CO 80301-2252

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
USAF, AFRL DUNS 143574726
AF OFFICE OF SCIENTIFIC RESEARCH
875 N. RANDOLPH ST. ROOM 3112 ARLINGTON VA 22203
MEHWISH G. KHAN 703 696-1092 mehwish.khan@afosr.af.mil

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION A

13. SUPPLEMENTARY NOTES

14. ABSTRACT
We have successfully completed the instrument construction. The unexpected issue with Ivory Coast import duty has prevented us from deploying the FPI in Ivory Coast as originally planned. However, by improvising we were able to construct a small FPI and have it deployed in Abuja, Nigeria and obtained thermospheric winds in West Africa for the first time. We are also able to simulate the R-T growth rate using the NCAR TIEGCM to study the longitudinal variations due to nonmigrating tides and solar effect on the R-T growth rate. These efforts will lay the foundation for future development of forecast capability of plasma bubbles. Due to delay in deploying the instruments, we were not able to validate the TIEGCM results with new observations from Africa. However, the new instrument in Africa will pave the way for new understanding of the equatorial aeronomy in Africa. Overall, the project is a good start for both modeling and observational efforts on equatorial aeronomy study in Africa. During a recent International Symposium on Equatorial Aeronomy in Ethiopia, we met many colleagues from Africa, who are greatly interested in the new observational results from Africa. We are looking forward to more collaboration in the future.

15. SUBJECT TERMS
Equatorial ionosphere, plasma bubble, thermospheric wind observations.

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	9	Qian Wu
					19b. TELEPHONE NUMBER *(Include area code)* 3034972176

Reset

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/ monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

Final Report
Low Latitude Aeronomy Study in Africa

a. INSTITUTE

National Center for Atmospheric Research
High Altitude Observatory
3090 Center Green Dr.
Boulder, Co 80301 USA

b. TITLE OF INVESTIGATION:

Low Latitude Aeronomy Study in Africa

c. PRINCIPAL INVESTIGATOR:

Dr. Qian Wu
Voice: 303 -497-2176
Fax: 303-497-2180
qwu@ucar.edu

d. REPORTING MONTH:

04/15/2013-04/14/2016 - ***Final***

e. IDENTIFICATION:

Grant Number: FA9550-13-1-0174

f. DATE OF SUBMISSION:

Feb 2015

1. Project Overview

The main objective of this project is to study the longitudinal variations of the plasma bubble and its association with the thermospheric wind. To achieve this goal, we proposed to deploy a Fabry-Perot interferometer in the West African nation of Ivory Coast to measure thermospheric winds. The reason we want to go to Africa is because the plasma bubble occurrence is large in Africa and we do not understand why. Because the Rayleigh-Taylor instability is responsible for the plasma bubbles, we also plan to use the TIEGCM to calculate the Rayleigh-Taylor (R-T) instability to understand how the neutral wind affects the R-T growth rate. The new observations will help validate the simulation results from the TIEGCM.

2. Accomplishments

2.1 Instrument Building

Figure 1. The instrument undergoing endurance test in the lab (top), FPI computer electronics (bottom left) and user interface (bottom right).

During the first year of the project, the major effort was on instrument building. The task was successfully completed (Figure 1). The instrument completed endurance test in the lab and was packed and ready for shipment.

2.2 Instrument Deployment Preparation in Ivory Coast

NCAR also worked closely with our Ivory Coast colleagues to make the necessary preparation for the site. An optical dome was acquired and an aluminum base plate was attached to the optical dome for mounting on the top of the house for the instrument. The dome was also packed and ready for shipping. NCAR also obtained an export license for instrument to be shipped to Ivory Coast. Our Ivory Coast colleagues constructed a new hut to house the FPI with their funding (Figure 2).

Figure 2. The hut (under construction earlier in 2015) in Korhogo Ivory Coast for housing the FPI. The hut should be ready by now.

2.3 Deployment of small FPI

During the first year, we have finished building of the instrument, which was packed in crates and ready for shipping. However, the instrument stayed at NCAR, because of an unexpected hurdle in shipping the instrument to Ivory Coast. The Ivory Coast custom requires substantial import duty for the instrument. Our Ivory Coast colleagues had anticipated that the import duty would be waived. Consequently, the deployment in Ivory Coast was not realized.

However, in order to provide much needed observations in Africa, we built a small FPI for the redline nightglow (630nm) thermospheric wind observation only. The large FPI built for Ivory Coast cannot be deployed easily without dedicated local facility. As a result, we could not just deploy the large FPI to other locations. A small FPI, on the other hand, is more flexible and allows more deployment options. In our first attempt, we went to Cape Verde Atmospheric Observatory, which is a British and German joint atmospheric research facility. The facility has reliable power and internet link. The project PI went to Cape Verde and deployed the instrument at the observatory (Figure 3). However, because the site is on the coast and the environment is very humid. It is not good for long-term optical instrument with the enclosure we built. After careful consideration, we decide to take the instrument back to NCAR.

Figure 3. The small FPI (left) and Cape Verde Atmospheric Observatory (right). The FPI was on the small tower on the left.

We presented preliminary results from Cape Verde during the International Symposium on Equatorial Aeronomy in Bahir Dar, Ethiopia in 2015. We compared Cape Verde observations with that from Arecibo, which is at the same geographic latitude as Cape Verde but higher geomagnetic latitude. We had anticipated some differences in the thermospheric winds because Cape Verde is under the Equatorial Ionosphere Anomaly (EIA), where the ion drag should be greater leading to smaller neutral winds. However, we did not find any significant differences in the zonal winds between the two locations (Figure 4) under clear sky (later half of the night). A further simulation with the TIEGCM will be conducted to examine the effect of the ion drag in the EIA. This is the first time an FPI making thermospheric winds observation off the coast of the Africa. The results are intriguing. It is regret that we do not have a longer data set. We hope that we will have the opportunity to deploy an instrument in Cape Verde for long term observations in the future. Cape Verde observations can help bridge the gap between the African and American sectors.

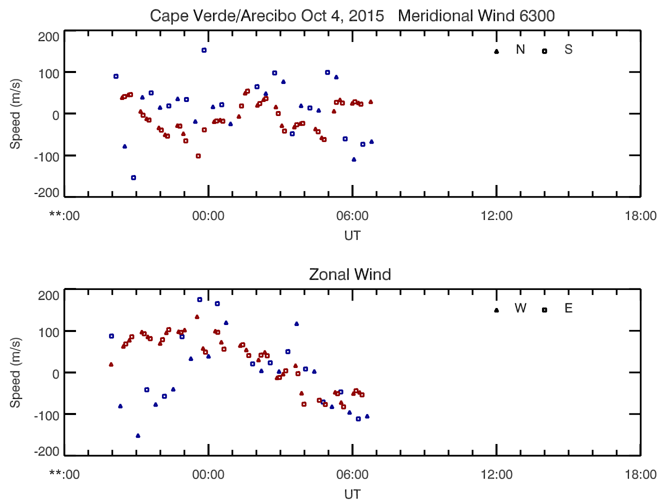

Figure 4. The Thermospheric winds comparison between Cape Verde (blue) and Arecibo (red). The Arecibo data are shifted by 3 hours so the two data sets are in the same local times. The early part of the Cape Verde data may be affected by cloudy weather.

For the second deployment attempt, we selected Abuja, Nigeria. Our Nigerian colleagues were very supportive and they have a building dedicated to the optical instruments. Prof. Shiokawa of Nagoya University has already deployed an all sky camera in the same building. The PI went to Abuja and deployed the instrument with strong support from the Nigeria Space Research and Development Agency. The instrument was deployed and operational. Because of the delay, the instrument deployment came near the end of the project. We do not have much time to analyze the new observational results from Abuja (Figure 5).

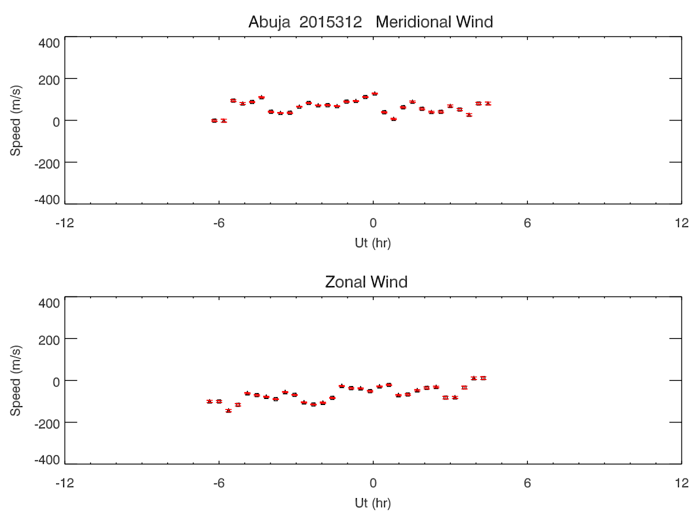

Figure 5. Preliminary thermospheric wind data from Abuja (top). The small FPI in Abuja (bottom left) and observatory in Abuja (bottom right).

We have not given up the deployment at Ivory Coast. Only recently (late January 2016), our Ivory Coast colleague Prof. Vafi Doumbia has found a solution to the import duty problem. Unfortunately, after the two Africa deployment trips, we cannot deploy the large FPI to Ivory Coast under this research grant without additional funding. We will write another proposal to AFOSR to continue this effort of deploying instruments in Africa to study low latitude aeronomy in Africa and support other investigators with new observational results. The instrument is ready for shipment and deployment.

2.4 Model Simulations

While the instrument deployment was delayed, we have started model simulations for the Rayleigh-Taylor (R-T) instability growth rate using the NCAR TIEGCM, which is part of our proposed research effort. The R-T instability is responsible for the plasma bubble. The simulated R-T growth rate distribution resembles the distribution of the occurrence of the bubble. A JGR paper was published on the influence of the nonmigrating tide on the R-T growth rate. We found that nonmigrating tide has a significant influence on the R-T growth rate particularly during solar minimum. The effect of the diurnal eastward propagating zonal wave number 3 (DE3) nonmigrating tide effect is very apparent in the simulation results (Figure 6). The effect of the DE3 on the R-T growth rate is closely connected the thermospheric zonal wind, which is modulated by the DE3. Thermospheric zonal wind can change the vertical ion drift, which can alter the R-T growth rate [*Wu*, 2015].

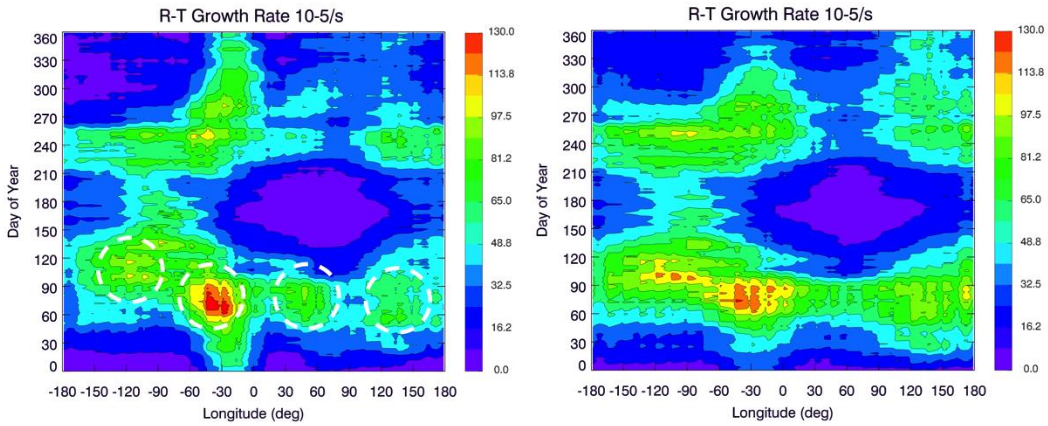

Figure 6. R-T growth rate with nonmigrating tide effect (left) and without (right) [*Wu*, 2015]. The DE3 features are highlighted with white dashed-line cycles.

We also investigated the solar influence on the R-T growth rate. The TIEGCM simulations of R-T growth rate for solar minimum and maximum are consistent with observed bubble occurrences under the respective solar conditions (Figure 7). Similarly to influence of the nonmigrating tides, the solar effect is also closely connected with the thermospheric zonal winds. During solar maximum, the zonal winds are greatly enhanced due to strong solar heating in the thermosphere. Consequently, the vertical ion drift was also increased through dynamo effect. In turn, the R-T growth rate also elevated. We just submitted a paper to JGR related to the solar effect on the R-T growth rate [*Wu*, 2016].

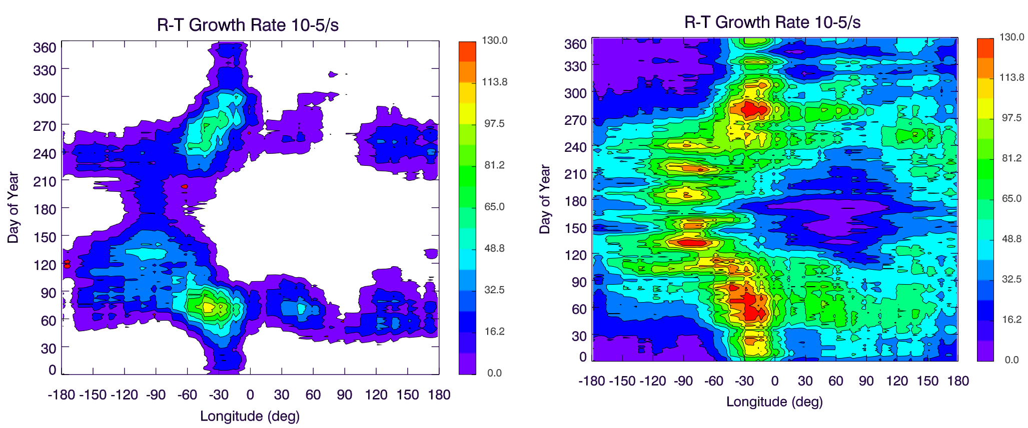

Figure 7. R-T growth rate during solar minimum (left) and maximum (right) [*Wu*, 2016].

While the TIEGCM simulations give largely consistent results, there are still discrepancies between the simulated R-T growth rate and plasma bubble occurrence distributions. The issues in the TIEGCM can only be mitigated through validation with observations. Since the thermospheric winds are the key of the R-T growth rate, thermospheric wind observations are very important for future improvement of the

TIEGCM and the development of forecast capability of the plasma bubbles. The FPI observations in Africa will play an important role in the future.

3. Summary

We have successfully completed the instrument construction. The unexpected issue with Ivory Coast import duty has prevented us from deploying the FPI in Ivory Coast as originally planned. However, by improvising we were able to construct a small FPI and have it deployed in Abuja, Nigeria and obtained thermospheric winds in West Africa for the first time.

We are also able to simulate the R-T growth rate using the NCAR TIEGCM to study the longitudinal variations due to nonmigrating tides and solar effect on the R-T growth rate. These efforts will lay the foundation for future development of forecast capability of plasma bubbles.

Due to delay in deploying the instruments, we were not able to validate the TIEGCM results with new observations from Africa. However, the new instrument in Africa will pave the way for new understanding of the equatorial aeronomy in Africa.

Overall, the project is a very good start for both modeling and observational efforts on equatorial aeronomy study in Africa. During a recent International Symposium on Equatorial Aeronomy in Ethiopia, we met many colleagues from Africa, who are greatly interested in the new observational results from Africa. We are looking forward to more collaboration in the future.

Publications

Wu, Q., J. Noto, R. Kerr, S. Kapali, J. Riccobono, W. Wang, and E. R. Talaat (2014), First Palmer and Millstone Hill midlatitude conjugate observation of thermospheric winds, *J. Geophys. Res. Space Physics,119*, doi:10.1002/2013JA019062.

Deng, Y., Y. Huang, Q. Wu, J. Noto, D. Drob, and R. B. Kerr (2014), Comparison of the neutral wind seasonal variation from midlatitude conjugate observations, *J. Geophys. Res. Space Physics, 119*, doi:10.1002/2013JA019716.

Wu, Q. (2015), Longitudinal and seasonal variation of the equatorial flux tube integrated Rayleigh-Taylor instability growth rate, J. Geophys. Res. Space Physics, 120, 7952–7957, doi:10.1002/2015JA021553.

Wu, Q., (2016), Solar Effect on the Rayleigh-Taylor instability growth rate as simulated by the NCAR TIEGCM, J. Geophys. Res., Space Physics, under review.

Presentations

1. Wu, Q., Vafi Doumbia, A new Fabry-Perot interferometer for Korhogo, Cote d'Ivoire (9.33N, 5.43W), CEDAR workshop, Boulder, Co June, 2013.
2. Emery, B. A. Preeti Bhaneja, Dieter Bilitza; Jorge L. Chau; William R. Coley; Douglas P. Drob; Tzu-Wei Fang; Bela G. Fejer; Benjamin T. Foster; Kathrin Haeusler; McArthur Jones; Jeffrey Klenzing; Hermann Luhr; John M. Retterer; Arthur D. Richmond; Patrick A. Roddy; Russell Stoneback; Yi-Jiun Su; Qian Wu; Xiaoli Zhang, Matching CHAMP and C/NOFS Climatology at Low Latitudes with the ionosphere-thermosphere TIEGCM and the plasmasphere GIP Models, AGU Meeting of the Americas, Cancun, May 2013.
3. Yamazaki, Y., A. D. Richmond, A. Maute, Q. Wu, Geomagnetic solar-quiet (Sq) variation: NCAR model vs. Ground magnetometer observations for Nov 2009, IAGA, 2013.
4. Wu, Qian, Thermospheric wind observations and simulations, SCOSTEP's 13th Quadrennial Solar-Terrestrial physics symposium, Xian, Oct 12, 2014.
5. Wu Qian, Thermospheric wind observation and space weather research at NCAR, Space Weather Workshop, Boulder, Co April 15, 2015.
6. Wu, Qian, J. Noto, Vafi Doumbia, Babatunde Radiu, Study longitudinal variations of the equatorial spread F occurrence by modeling and observations, 14th International Symposium on Equatorial Aeronomy, Bahir Dar, Ethiopia, Oct 19, 2015.