Centre for Atmospheric Research

2018 MONOGRAPH OF ATMOSPHERIC RESEARCH

Edited by **A.B. Rabiu and O. E. Abiye**

A Publication of
CENTRE FOR ATMOSPHERIC RESEARCH
National Space Research and Development Agency
Federal Ministry of Science & Technology

Centre for Atmospheric Research

2018 MONOGRAPH OF ATMOSPHERIC RESEARCH

Edited by A.B. Rabiu and O. E. Abiye

A Publication of
CENTRE FOR ATMOSPHERIC RESEARCH
National Space Research and Development Agency
Federal Ministry of Science & Technology

MONOGRAPH OF ATMOSPHERIC RESEARCH 2018

First Published in 2018

ISBN: 978-978-972-859-6

Printed in Nigeria
by Simplicity Press
Tel. +234 (0)803 085 1374
Email: dapoashaolu@yahoo.com

PREFACE

The Centre for Atmospheric Research was established in January 2013 with a compelling mission to improve our understanding of the behaviour of the entire spectrum of the Earth's atmosphere; promote capacity development in relevant atmospheric sciences as a way of facilitating international competitiveness in research being conducted by atmospheric scientists; and disseminate atmospheric data/products to users towards socio-economic development of the Nation. CAR's extant core research focus includes: space weather, tropospheric studies, atmospheric research software and instrumentation development, microgravity and human space technology, and atmospheric chemistry and environmental research.

Pursuant to the above, The *Monograph of Atmospheric Research* published by the Centre for Atmospheric Research (CAR), is a collection of peer-reviewed manuscripts in Atmospheric Sciences and closely related fields. This maiden edition comprises articles presented during two separate workshops; *1st National Workshop on Microgravity and Environmental Research* (26 - 29 November, 2017) and *1st National Workshop on Air Quality* (13 - 16 March, 2018). Such workshops are integral part of CAR's capacity building program and they were primarily aimed at advancing the course of atmospheric research in Nigeria towards sustainable development. The Microgravity workshop was geared towards introducing new research opportunities in space life science by simulating microgravity conditions here at the earth's surface as a means of investigation space biological environment. The Air Quality workshop was organized in collaboration with Ministry of Environment and Nigerian Meteorological Agency (NIMET). The workshop analysed current Air Quality scenario in Nigeria, explored new opportunities for collaborative research and offered novel means of improving the present quality of life of the populace without jeopardizing the chance of the future generation. Cumulatively 196 participants participated in these two workshops and about 52 articles were eventually submitted for publication consideration in this monograph. The twenty-one articles in this very monograph are the articles that eventually made it through the rigorous peer-review process. We remain grateful to the reviewers for doing thorough work on the articles.

Thus, we are very pleased to present the *2018 Monograph of Atmospheric Research* which contains twenty-one articles, including some review papers, to readers in all spheres of interest across Nigeria and beyond. It is our hope that this effort will continue and will serve as a reference to atmospheric researchers in Nigeria.

Prof. A. B. Rabiu and Dr. O. E. Abiye,
Editors

Centre for Atmospheric Research

Preliminary assessment of cloud-pollution-precipitation interactions and intra-event trends over a tropical region using vertically-pointing Micro Rain Radar.

J. S. Ojo[1*], O. L. Ojo[2], A. Oluleye[3] and A. C. Tomiwa[4]

[1]Department of Physics, Federal University of Technology Akure, Nigeria.
[2]Department of Physics, Adeyemi College of Education, Ondo, Nigeria.
[3]Department of Meteorology and Climate Science, Federal University of Technology Akure, Nigeria
[2]Department of Physics and Electronics, Adekunle Ajasin University,Akungba-Akoko, Nigeria
E-mail: josnno@yahoo.com,
Tel: +2348066532234

ABSTRACT

Water-soluble aerosols play important roles especially in the area of air quality and environmental development. They act as cloud pollution due to atmospheric turbulent leading to instability in the formation of water droplets at a specified relative humidity. This invariably affects processes involved in precipitation and cloud formation. There is therefore an urgent need to assess the cloud-pollution–precipitation interaction based on intra-event samples at different seasons and a range of synoptic conditions. This study analyses the possible interaction among the cloud-pollution–precipitation for environmental development in an urban tropical area. Precipitation events as characterized by rain rate, fall velocity, drop size distributions and radar reflectivity were observed using a vertically-pointing micro rain radar (MRR) for a period of 2 years (October 2010 to October 2012). The overall results will be applicable in the area of cloud resolving models, and an improved insights into different environmental processes due to precipitation events.

Keywords: Cloud-pollution, Aerosols, Intra-event, Precipitation events, Micro rain radar.

Citation: Ojo, J. S., Ojo, O. L., Oluleye, A. and Tomiwa, A. C., 2018. Preliminary assessment of cloud-pollution-precipitation interactions and intra-event trends over a tropical region using vertically-pointing micro rain radar. Monograph of Atmospheric Research 2018, Edited by A. B. Rabiu and O. E. Abiye, Centre for Atmospheric Research, Anyigba, Nigeria. pp. 47-51.

INTRODUCTION

Water-soluble aerosols play important roles especially in the area of air quality and environmental development. They act as cloud pollution due to atmospheric turbulent leading to instability in the formation of water droplets at a specified relative humidity. This invariably affects processes involved in precipitation and cloud formation. The effect can be categorized into direct and indirect. The direct effects which are due to absorption and scattering of solar radiation, while the indirect effects can be as a result of the action of aerosols as cloud condensation nuclei (CCN), thereby affecting the initial cloud droplet number concentration, precipitation formation, and lifetime of warm clouds (*Muller et al., 2010*). The indirect effects of aerosol on clouds pose a great challenge in terms of investigation from both the observational and modelling point of view. This has prompted atmospheric scientists to explore the impact of increasing anthropogenic activities on cloud and precipitation processes.

There is therefore an urgent need to assess the cloud-pollution–precipitation interaction based on intra-event samples at different seasons and a range of synoptic conditions (*Pruppacher and Klett, 2000*). Studies revealed that small particle droplets (aerosols) narrows the size distribution of cloud droplets, thereby leading to reduction in precipitation, since a range of droplet sizes are required for warm rain to develop (*Shepherd, 2005, Muller et al., 2010*).

Moreover, large CCN increases the formation of precipitation through the ice phase, due to formation of ice by nucleation. That is, large droplets formed by the giant CCN produce graupel particles with high coagulation efficiency with drops and therefore grow more rapidly as they are lifted in the updraft region, yet they remain close to the cloud base which can also promote ice multiplication processes in super cooled regions according to *Yin et al. (2000)*. Hence, the impact of aerosols on the precipitation processes cannot be overemphasized: they can either enhance or suppress precipitation depending upon type of aerosol, seasonality, climate regime, cloud type or orographic profile of a region, particularly over populated areas (*Shepherd et al., 2002*).

For the purpose of this work, a ground-based remote-sensing techniques has been employed to observe and examine both cloud and precipitation processes. Qualitatively examination of precipitation forming processes, such as, cloud drop size, which is a major factor in cloud microstructure that determines their precipitation forming processes. Precipitation events as characterized by rain rate, fall velocity, drop size distributions and radar reflectivity were observed using a vertically-pointing micro rain radar (MRR) for a period of 2 years (2010-2012) in an urban tropical area (Akure). The MRR was originally designed to measure rain parameters according to Peters et al., (2002); however based on recent modifications in the MRR data processing and comparisons to cloud radar observations it have been revealed that the MRR can also be used to study snowfall (*Kneifel et al., 2011, Stark et al., 2013*). More recently, vertically-pointing radars have been introduced to study high-resolution sampling of precipitation events (*Maahn et al., 2014*). The rest of the paper are structured as thus: Firstly, site characteristics and methodology adopted are discussed and instrumentation details are also provided. Secondly, events are classified according to their precipitation microstructure based on the drop sizes distribution (DSD), and the corresponding implications are examined for each class for the selected number of case studies. Finally, conclusions are drawn and recommendations suggested based on the preliminary investigation. However, results on the examination of the content of precipitation samples using Pioneering Fluorescence Spectrophotometry Technique (PSFT) are not presented in the present paper.

METHODOLOGY

The experimental site is the Communication Research Observatory (CRO) situated at the Department of Physics, Federal University of Technology, Akure (7°15'N, 5° 15'E) in the Southwestern part of Nigeria at an altitude of 160 m above sea level.

The ground-based remote-sensing techniques is adopted for this work. The main equipment used for this work is the Micro Rain Radar (MRR), manufactured by METEK. It is a vertically pointing frequency-modulated continuous-wave (FM-CW) radar. MRR operates at the K-band spectrum with a wavelength of 1.25 cm and operating frequency of 24.1 GHz. The frequency is modulated between 1.5 and 15 MHz. Table 1 shows the characteristic of the MRR used. The outdoor unit of the instrument is located on the measurement platform of the observatory garden while the indoor unit is housed in the scintillation lab. Figure 1 also shows the outdoor and indoor units of the MRR.

The vertical profiles of rain parameters were observed using an MRR. It has an instantaneous measurement at every 10 s integrated over 1-min with a vertical resolution of 160 m. The 160 m resolution is taken to accommodate the nearly complete profile of the rain up to 4800 m over this region with a total of 30 range gates.

The radiation emitted from the MRR usually hits an upcoming raindrop, hail, snowflake or some other form of precipitation with a different frequency and reflected back to the MRR. The Doppler shift of frequency makes it possible for the MRR to determine the fall velocities of droplets and to calculate drop spectra and rain rates. It is therefore capable of determining DSDs from the Doppler spectra utilizing the relation between drop size and terminal fall velocity according to *Atlas et al.* (1973). The DSD (expressed as the number of drops per cubic meter of air per millimeter diameter, $m^{-3}\ mm^{-1}$), is dependent upon the precipitation processes during raindrop formation, growth, transformation and decay occurring on a microphysical scale within the cloud environment (*Roy et al., 2005*).

Table 1. Characteristics of the MRR

Radar Parameters	Specifications
Radar system type (Modulation)	FM-CW
Frequency (GHz)	24.1
Transmit power	50 mW
Antenna	Off-set parabolic with 0.6 m diameter
Beam width (2-way, 6 dB)	2°
Range resolution	160 m
Minimum detectable radar reflectivity	-2 dBZ
No of range gate	30
Nyquist velocity range	0–12.3 ms^{-1}
No. of spectral bins	64

(a)

(b)

Figure 1: MRR diagram (a) outdoor unit and (b) Indoor unit

The equipment measures the backscatter of radiation from precipitation-sized particles from the surface up to 4800 m, enabling a number of parameters to be generated including the fall velocity (*W*), drop size distribution (DSD) — which varies greatly with precipitation type and rate—liquid water content (*LWC*), rain rate (*R*) and reflectivity (*Z*), allowing the microstructure of the precipitation to be analyzed. Based on the initial data sorting, the 160 m height bin was found to underestimate precipitation, this might be due to the ground level turbulence, and hence data from 320 m height bin was used for analyzing ground level precipitation.

For the rain rate parameterizations, we selected the rainy days in all the two years of measurement for the analysis and find the mean values. All data were classified into 0.5 mm/h classes at different heights resolution of 160 m and the 30th range gate corresponds to 4800 m. MRR Doppler spectrum (after noise subtraction), DSD grouped in 43 classes with drop diameters from 0.249 to 4.6 mm are estimated.

This was further categorized into rain types using temperature-effective radius relationship (T-r_e) for further analysis and each of rain parameters were modeled along the profile with the DSD to assess the interactions, and spatial and temporal variations, occurring during individual precipitation events.

Although not included in this report, examination of the content of precipitation samples will be carried out in the subsequent studies using a Pioneering fluorescence spectrophotometry technique (PSFT) in order to assess the dissolved organic carbon (DOC) content. The technique has been known to provide a non-invasive, rapid method to examine the content of precipitation samples.

RESULTS AND DISCUSSION

Results are presented firstly for vertical profile of a number of parameters for a typical precipitation events. DSD curves for all the events that were classified as stratiform, convective and mixed (stratiform-convective) according to the T-r_e are also presented. Figures 2-4 are for typical precipitation events on the 26th October, 2010, 30th October, 2011 and 22nd September, 2012 respectively. Rain drops of different diameters have different falling velocities and thus the DSD can be obtained and be used to determine rain rate as an alternative method to the usual Z–R relation of weather radars (*Muller et al., 2010*). The presence of polluted clouds could be observed around 16:40 to 16:50 hrs LT of the day as presented in Figure 2 while the presence of polluted clouds as well as super cooled water clouds could be observed in Figures 3 and 4. Although analysis will be needed to ascertain the nature as well as the level of the pollution involved. Further results from Figure 2 revealed that bright band was clearly observed around 16.20 LT and at 16.31 LT, partial one was observed while around 17.00 LT, there is no bright band. These show the complete transformation from stratiform to mixed and convective rain type respectively. Convective rain is associated with vertical wind motion thus hindering formation of melting layer. In addition, when there is bright band, the rain rate at lower heights has low values as real evidence of stratiform condition. Moreover, when the radar bright band is absent, the rain rate at lower heights are found to be high in the present spectrum, which could be categorized as convective rain as reported in the work of Cha et al., 2007.

In addition, most rain drops originate from the melting of ice hydrometeors that are typically graupel or hail in the convective elements, and snowflakes in the mature or stratiform cloud (*Rosenfield and Ulbrich,2003*). Graupel and hail grow without breakup while falling through the supercooled portion of the cloud and grow by accretion in the warm part of the cloud, where they melt. Large melting hail stones releases the excess melt-water in the form of a DSD. Releasing excess melt-water stops when the melting particles approach the size of the largest stable raindrops. Although, these are subject to further break up as a result of further collisions with other raindrops. Hence, formation of new raindrop is limited to the breakup of pre-existing larger raindrops.

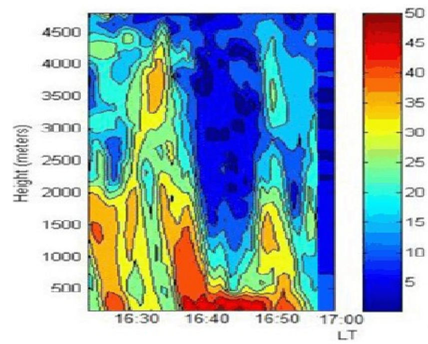


Figure 2: A typical "Air Mass" with 'polluted' case-16:20-17:10 GMT LT of 26th October 2010.

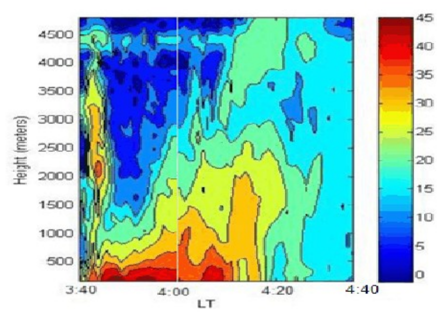


Figure 3: A typical "Microphysical": Precipitating cloud, super cooled water clouds in places 03:40 to 04:50 GMT LT of 31st October 2011 and polluted cases.

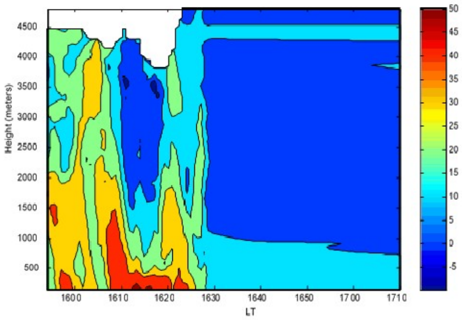
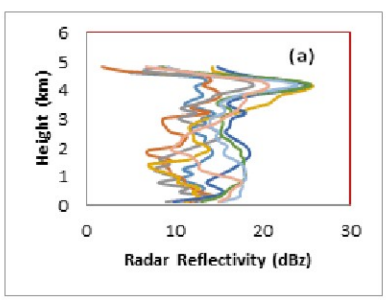
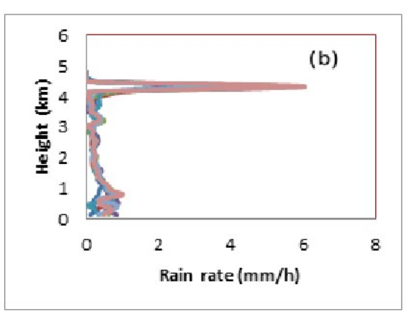
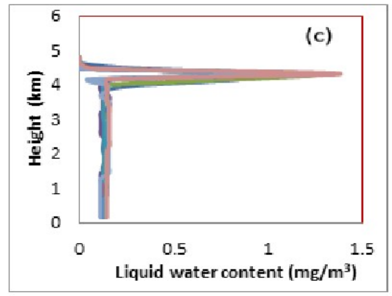


Figure 4: A typical "Air Mass": precipitating cloud, with super cooled water clouds and polluted cases-16:00 to 17:10 GMT LT of 22nd September 2012 and polluted cases.

Figures 5a -5d also present the vertical profiles of different rain parameters as obtained from MRR during the rain event on 26th October, 2010 from 16:20 and 16:30 LT. The radar reflectivity profile indicates a clear peak at 4.3 km that corresponds to the melting layer as presented in Figure 5 (a). It is also noted that around the same height, rain rate attained its peak values (Fig. 5b). The plot of the vertical profiles of liquid water content also has a peak around the same height of 4.3 km as presented in Figure 5 (c). However, the vertical profile of average fall velocity shows a small enlargement near 4.2 km (Figure 5d). This is in agreement with observations from the work of *Peter et al. (2002)* and the two papers reported that the average fall velocity appears at a certain peak due to melting layer.







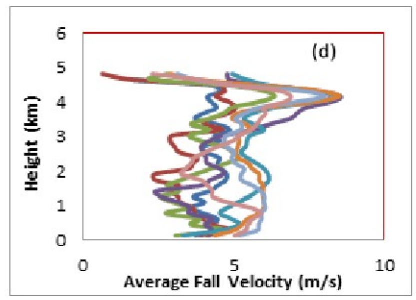


Figure 5: Vertical profiles of rain parameters for (a) Radar reflectivity (b) Rain rate (c) Liquid water content and (d) Average fall velocity.

Figure 6 presents the mean DSD plot for stratiform, convective and mixed (stratiform-convective) events. The results show that DSD varies with the dynamics of the cloud: evident in the extreme cases of convective, stratiform and mixed. The convective events have fewer droplets <2 mm compared to stratiform events. Comparison based on the individual DSDs show that a large number of convective events have fewer smaller droplets (<1 mm) compared to stratiform events. DSD curves also follow a similar sequence of transitions as for cloud microphysics, with convective precipitation containing a greater number of larger raindrops. One factor affecting the resulting DSD is greater updrafts where the smallest droplets are deposited in the aloft, especially in thunderstorms rain types. According to Roy et al. (2005) the shape of the DSD curve can actually be used to help determine type of precipitation, based on the fact that riming is the main process determining the form of the DSD in convective clouds which is an indication of updrafts and convection while aggregation is the main process determining stratiform DSD. It should be noted that further analysis using the Pioneering fluorescence spectrophotometry technique (PSFT) will assist in the association of DSD with aerosol concentration based on the precipitation intensity and droplet spectra.

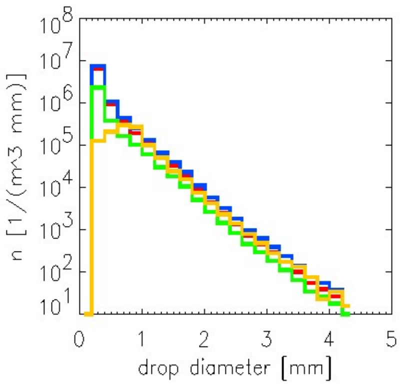


Figure 6: A typical results showing different DSD.

CONCLUSION

This paper has examined the preliminary results based on a number of precipitation events using a vertically-looking remote sensing radar techniques, and has categorized each event in order to examine the overall trends. Results show that, over the study location, small changes in cloud microstructure can have impacts on the resulting precipitation. When storm dynamics was examined, convective events appeared to contain fewer smaller droplets compared to stratiform events. It is evidence that there are some differences between the DSD for different events when classified according to source, cloud microphysical structure and dynamic state, however, further analysis is needed to ascertain the level of pollution associated with such events.

Competing Interest

Authors have declared that no competing interests exist.

REFERENCES

Atlas D, Srivastava R and Selkon R, (1973). Doppler radar characteristics of precipitation at vertical incidence. Rev Geophys, Space Phys, 11, 1-35.

Cha, Joo-Wan, Seong, Soo Yum, Chang, Ki-Ho, Sung, Nam Oh (2007). Estimation of the melting layer from a Micro Rain Radar (MRR) data at the Cloud Physics Observation System (CPOS) site at Daegwallyeong Weather Station. APJAS 43 (1), 77–85.

Kneifel, S, Maahn M, Peter G and Simmer C, (2011). Observation of snowfall with a low-power FM-CW K-band radar (MRR), Meterolog Atmosp Phys, 113, 75-87.

Maahn, M., C. Burgard, S. Crewell, I. V. Gorodetskaya, S. Kneifel, S. Lhermitte, K. Van Tricht, and N. P. M. Lipzig, (2014). How does the spaceborne radar blind zone affect derived surface snowfall statistics in Polar Regions. Journal Geophysical Research Atmosphere, 119, 13 604–13 620, doi:https://doi.org/10.1002/2014JD022079.

Muller, C.L., C. Kidd, I.J. Fairchild and A. Baker, (2010). Investigation into clouds and precipitation over an urban area using micro rain radars, satellite remote sensing and fluorescence spectrophotometry, Atmospheric Research, 95, 241–255.

Peters, G., Fischer, B. and Andersson, T. (2002). Rain Observations with a vertically looking Micro Rain Radar (MRR), Boreal Environment Research, 7, 353-362.

Pruppacher, H.R. and Klett, J.D., (2000). Microphysics of Clouds and Precipitation, Second Revised and Enlarged Edition, Atmospheric and Oceanographic Sciences Library. Kluwer Academic Publishers.

Rosenfield D and Ulbrich C.W, (2003). Cloud microphysical properties, process and rainfall estimation opportunities, Meteorological Monographs 10, 217- 227.

Roy S.S, Datta R.K, Bhatia, R.C, and Sharma, A.K, (2005). Drop size distributions of tropical rain over South India, Geofizika, 22, 105-130.

Shepherd, J.M, (2005): A review of current investigations of urban-induced rainfall and recommendations for the future. Earth Interactions, 9, 1-27.

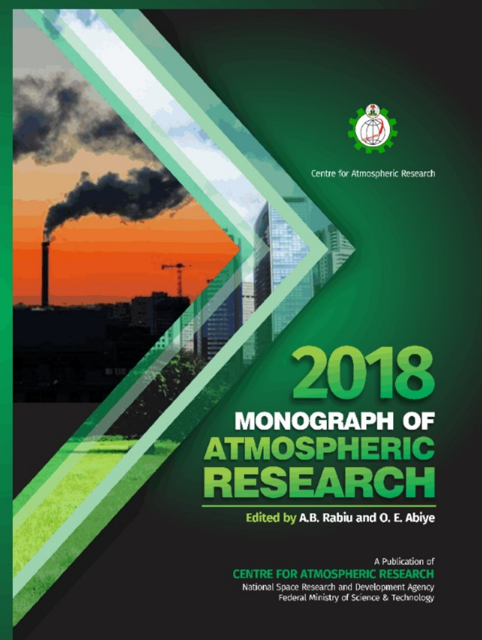
Shepherd, J.M, Pierce, H.F, Negril, A.J, (2002). Rainfall modification by major urban areas: observations from space borne rain radar on the TRMM satellite, Journal of Applied Meteorology 41, 689-701.

Stark, D., B. A. Colle, and S. E. Yuter, (2013). Observed microphysical evolution for two East Coast winter storms and the associated snow bands. Mon. Wea. Rev., 141, 2037–2057, doi:https://doi.org/10.1175/MWR-D-12-00276.1.

Yin Y., Levin, Z, Reisin T.G, Tzivion S, (2000). The effects of giant cloud condensation nuclei on the development of precipitation in convective clouds- a numerical study. Atmosphere Research 53, 91-116.

Centre for Atmospheric Research

National Space Research and Development Agency
Federal Ministry of Science & Technology



Our Mandates

The Center for Atmospheric Research, CAR, is a research and development center of NASRDA committed to research and capacity building in the atmospheric and related sciences. CAR shall be dedicated to understanding the atmosphere—the air around us—and the interconnected processes that make up the Earth system, from the ocean floor through the ionosphere to the Sun's core. The Center for Atmospheric Research provides research facilities, and services for the atmospheric and Earth sciences community.

Contact Address

Centre for Atmospheric Research,
National Space Research and Development Agency,
Federal Ministry of Science and Technology
Kogi State University Campus, Anyigba,
Kogi State - Nigeria.

Telephone: +234 8105793836
Email: info@carnasrda.com
Web: www.carnasrda.com

.... creating opportunities..............

ISBN 978-978-972-859-6